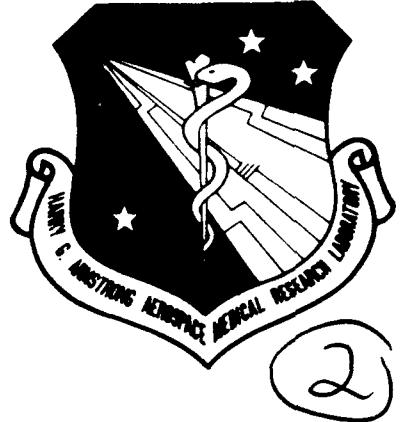


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HELMET-MOUNTED DISPLAY/SIGHT TACTICAL UTILITY STUDY (U)

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McDonnell Aircraft Company
McDonnell Douglas Corporation
P.O. Box 516
St. Louis, MO 63166

June 1988

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FOR THE COMMANDER


CHARLES BATES, JR.
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PREFACE

The work reported on herein was performed under Contract Number F33615-85-D-0514, Task 0013. This report, entitled "Helmet Mounted Display/ Sight Tactical Utility Study," covers the period August 1986 through October 1987 and the technical efforts concerning tactical applications of Helmet Mounted Display/ Sight. The portions of Task 0013 that concern strategic applications are documented in a separate technical report.

The impetus of this effort was a message written by the Fighter Requirements Division (TAC/DR) located at Tactical Air Command Headquarters requesting a study to be pursued to evaluate the tactical utility of current HMD/S systems integrated into F-15 aircraft performing air-to-air combat. To support this request, the Human Engineering Division developed a strategy to qualitatively and quantitatively evaluate HMD/S utility in as operational a setting as possible. This strategy involved utilizing manned simulation as a tool to support operational scenarios and threat mixes. This permitted operational F-15 pilots to combine the HMD/S capability with the current weapon deployment concepts and tactics. This strategy allowed maximum flexibility and variability in use of aircraft and HMD/S capability.

The following members of the Technical Staff of the Advanced Design group at the McDonnell Aircraft Company participated in this effort; P. King, C. Arbak, B. Waldron, R. Jauer, and E. Adam.

This task was conducted for the Armstrong Aerospace Medical Research Laboratory through the Southeastern Center for Electrical Engineering Education by McDonnell Douglas Corporation and Washington University under the technical direction of Mr. Michael Haas and Dr. John Pellosie. Other Air Force Agencies, such as the Tactical Air Command, provided invaluable consultation regarding operational considerations and mission scenario design. Lt. Col. Michael Gentrup (HQ/TAC/DRFA) and Lt. Col. Joe Farcht (ASD/TACSO) worked closely with AAMRL providing operational direction in the conceptual phase of the effort as well as during its period of performance and were instrumental in assuring its successful completion.



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1.0 INTRODUCTION

Visually coupled systems, under development at the Armstrong Aerospace Medical Research Laboratory (AAMRL) since 1966, have been advocated for use in high performance fighters. Helmet mounted sight/displays (HMS/D) are considered a prime method for enhancing pilot capabilities, especially in acquiring and maintaining "situation awareness," and the large off-boresight capability promises to provide improved combat effectiveness.

The VCSS (Visually Coupled System Simulation)-Vista Sabre Study was a funded program at MCAIR from the Southeastern Center for Electrical Engineering Education (SCEE). An objective of VCSS was to demonstrate the capabilities and benefits of a helmet mounted sight and display (HMS/D) to Tactical Air Command (TAC) pilots.

The purpose of this MCAIR report is to analyze the data generated by the VCSS study, draw conclusions and recommend further investigations of HMS/D systems.

The purpose of the VCSS study was to help the Air Force and industry develop displays and cockpits that help reduce workload, and increase situation awareness and system effectiveness. A man-in-the-loop simulation was used to collect data on equipment and concepts that have been developed.

The simulation objectives were to:

- 1) Demonstrate possible applications of an HMS/D to a TAC air-to-air mission.
- 2) Collect subjective workload data.
- 3) Determine a better way to integrate an HMS/D into an F-15.
- 4) Determine other applications of an HMS/D to TAC Missions.

Two F-15 cockpits were used for the "Blue" cockpits. One is an F-15C MSIP (multi-staged improvement program) cockpit. The other is an F-15E cockpit that was modified to respond as if it was an F-15C MSIP cockpit.

Two MICS (manned interactive control stations) were used for the "Red" cockpits.

The HMS/D used was the Agile Eye made by Kaiser Electronics. The Agile Eye is a new helmet design that incorporates the latest technology available to all functions of a flight helmet. It weighs only 2.6 lbs, or one-half pound lighter than the current lightweight helmet (Figure 1-1). It has a center-of-gravity (cg) that is near the cg of the pilot's head (Figure 1-2). The cg of current helmets is forward of the head cg which induces extra load on the pilot's neck during ejection. The aerodynamic design of Agile Eye reduces aero loads from 600 lbs with current helmets, in a 500 Kt ejection, to only 300 lbs.

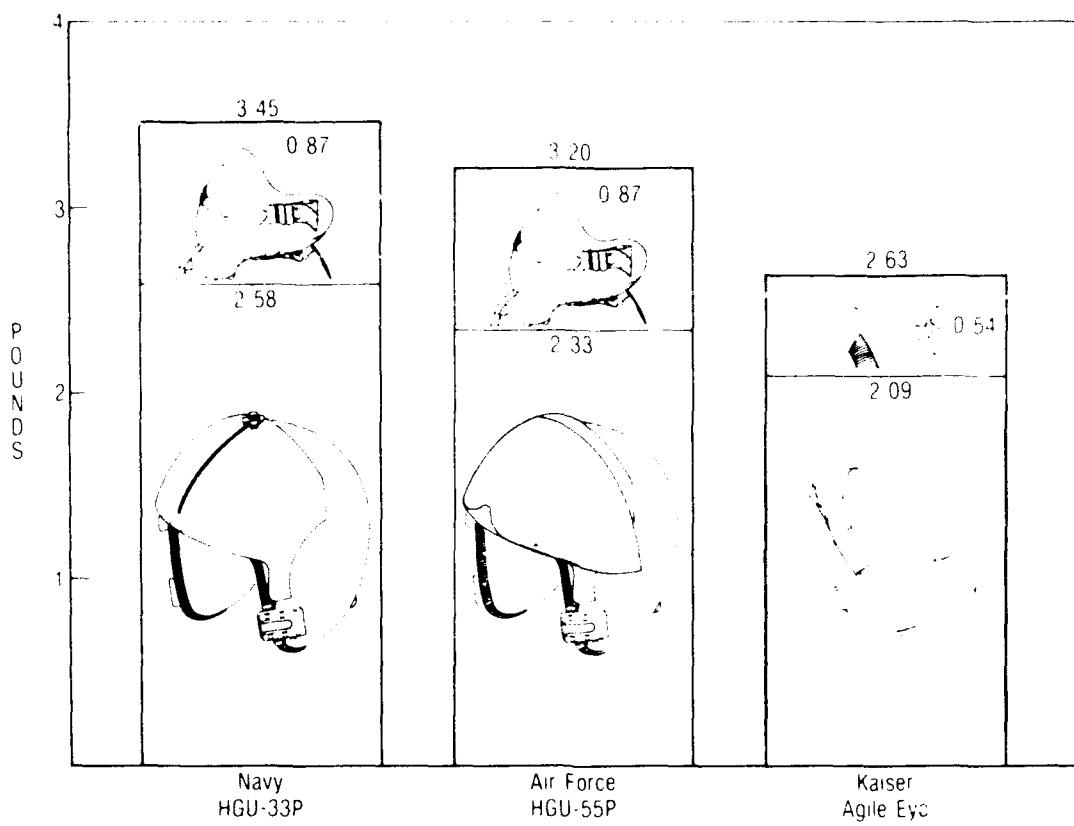
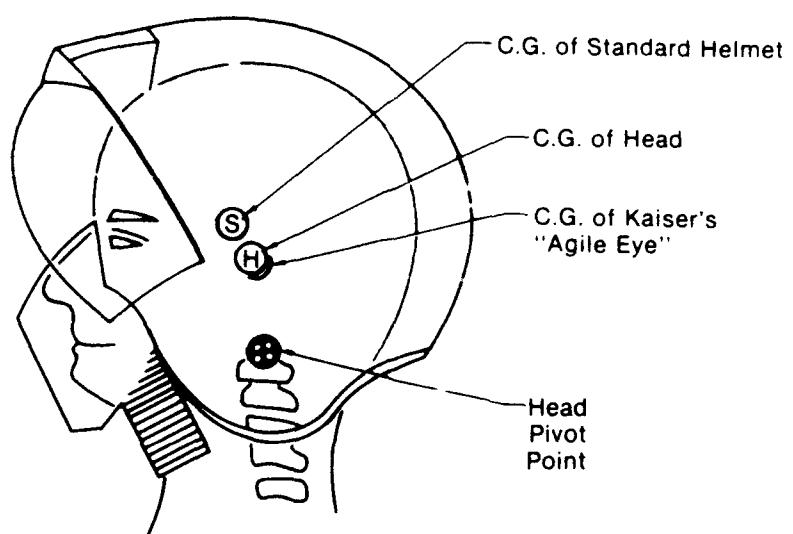


Figure 1-1. "Agile Eye" Weight

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Figure 1-2. "Agile Eye" C.G. Comparison

Proficiency using the HMS/D and flying in the simulator was developed with a combination of classroom briefings, study, and with trials, discussions and practice sessions in the simulator. During the experiments, normal crew tasks, such as flying, communicating, operating sensors (e.g., radar), responding to threats, acquiring targets, and launching weapons were performed. Debriefing was accomplished with questionnaires and interviews.

Two blue force pilots in F-15 simulators conducted 2v2, 2v4 and 2v8 air-to-air missions against digital opponents and two Aggressor pilots flying manned interactive combat stations (MICS). The HMS/D was used by the F-15 pilot to provide off boresight target acquisition, direct target detection and tracking with the radar and employee weapons.

The effectiveness of the HMS/D was evaluated by comparing identical missions conducted with and without the HMS/D. Performance data were collected on sensor employment, weapon usage, and exchange ratios in addition to subjective workload and opinion data. Data were recorded on a master data tape and printed off-line. Audio and video tape records of all missions were kept.

HMS/Display formats were jointly defined by MCAIR and AAMRL. MCAIR used display symbology and integration in concepts from the F-15C so that a minimum change was made to the basic system operation. Helmet display symbology was developed at MCAIR and evaluated at AAMRL prior to the full mission evaluation.

F-15C aerodynamics models were used along with integrated controls and displays.

2.0 SUMMARY

Two Agile Eye prototype helmet mounted sight and display (HMS/D) systems were evaluated with 30 hours of testing in two simulated F-15C MSIP aircraft in MCAIR's flight simulation facility. The test lasted two weeks. Each week had two TAC F-15 pilots fly with and without helmets in four test scenarios (2v2, 2v4, 2v8 and 1v1v1v1). Opposing the F-15s were a variety of aircraft. Two of the opponents were flown by Aggressor pilots from Nellis AFB. The other opponents were digital aircraft "flown" by the simulation computer.

The HMS/D concept was highly lauded by the pilots. They also noted some improvements needed for the prototype systems that they used for the test. These included better visor optics, a better/firmer fit, and a sharper focus of the display optics.

The measured data showed an initial slight decrease in performance while the pilots learned how to use the new capability. That was followed by a large increase in performance at the end of the testing period when the exchange ratio nearly doubled while it remained nearly constant without the HMS/D.

The pilot opinion data also strongly supported the HMS/D for the within-visual range (WVR) arena. The pilots were especially enthused about the time saved with the HMS/D, the capability it gave them to launch AIM-9 missiles while guiding an AIM-7 and the capability to launch AIM-9 missiles while keeping basic fighter maneuvering (BFM).

3.0 CREW STATIONS

An F-15C MSIP and an F-15E cockpit were used for the simulations. The F-15E was modified to function like an F-15C MSIP.

3.1 F-15C CREW STATIONS

The baseline aircraft was an F-15 with MSIP equipment, and operational flight program 1002 in the central computer and a CAJ radar tape. The Radar possessed track-while-scan (TWS) and raid assessment mode (RAM) capabilities.

3.2 CHANGES TO F-15C MSIP SYSTEMS

The following changes were made to the operation of the baseline aircraft:

- o The forward and aft positions of the auto acquisition switch on the stick were redefined when the radar was in a search mode. The forward position of the switch provided helmet automatic acquisition; the aft position had no function. The switch is shown in Figure 3-1.

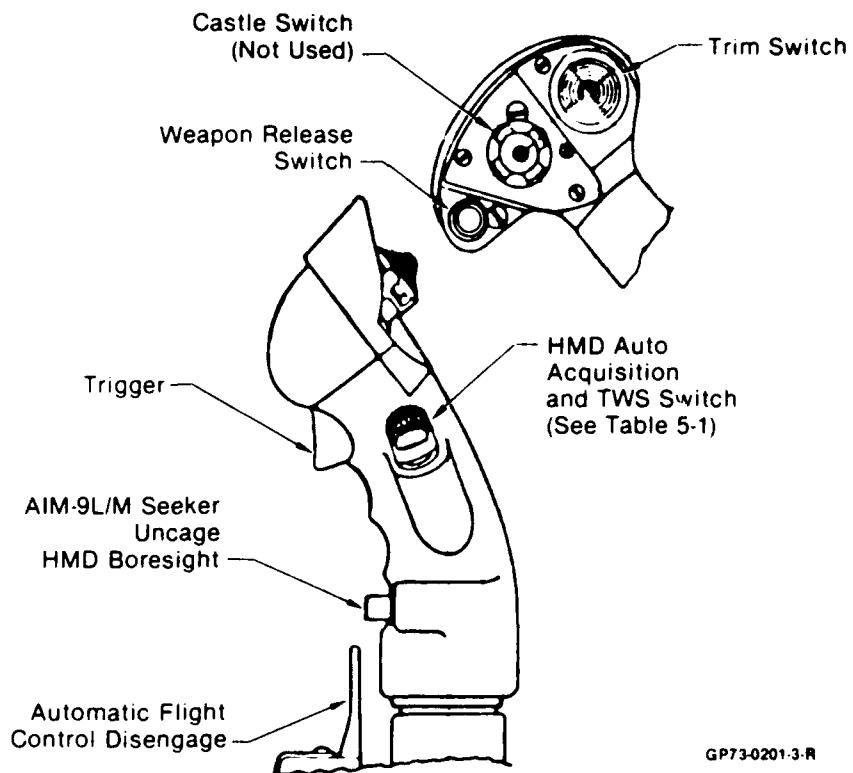


Figure 3-1. Stick Switch Functions

- o The Supersearch, Boresight, and Vertical Scan auto acquisition modes were replaced by two helmet auto acquisition modes: Helmet Supersearch (HSS) and Helmet Boresight (HBST). Auto Gun Scan was

still available as a third auto acquisition mode and operated in the same manner as on the MSIP F-15.

- o The HUD Symbols Reject switch also removed symbols from the Helmet Display.
- o The operation of the AIM-9 L/M seeker when not slaved to the radar was changed. Basically, all operations that previously resulted in slaving the seeker to aircraft boresight in the MSIP F-15 had the effect of slaving the seeker to the helmet line of sight (LOS).
- o Certain symbols were removed from the HUD when the HMD was in use to eliminate clutter (see Appendix A).

All other aircraft systems and displays of the baseline aircraft were unchanged and operated in the manner defined in T.O. IF-34C-1-1, Non-Nuclear Weapon Delivery Manual (Air-to-Air). This included operation of the auto acquisition switch with the radar in a track mode to obtain TWS or RAM modes.

3.2.1 Flight Control Stick - The HMD Auto Acquisition Switch Functions are depicted in Figures 3-1 and 3-2. Note that a castle switch was located where the trim switch is on F-15A and C models. For this simulation the castle switch was inoperative. The trim switch was located to the right of the castle switch.

Auto Acquisition Switch Position	Radar Mode	
	Search	STT
Forward	1 = HMD Supersearch 2 = HMD Boresight	1 = HD-TWS 2 = STT *
Aft	No Function	1 = TWS 2 = STT
Down	Return to Search	Return to Search

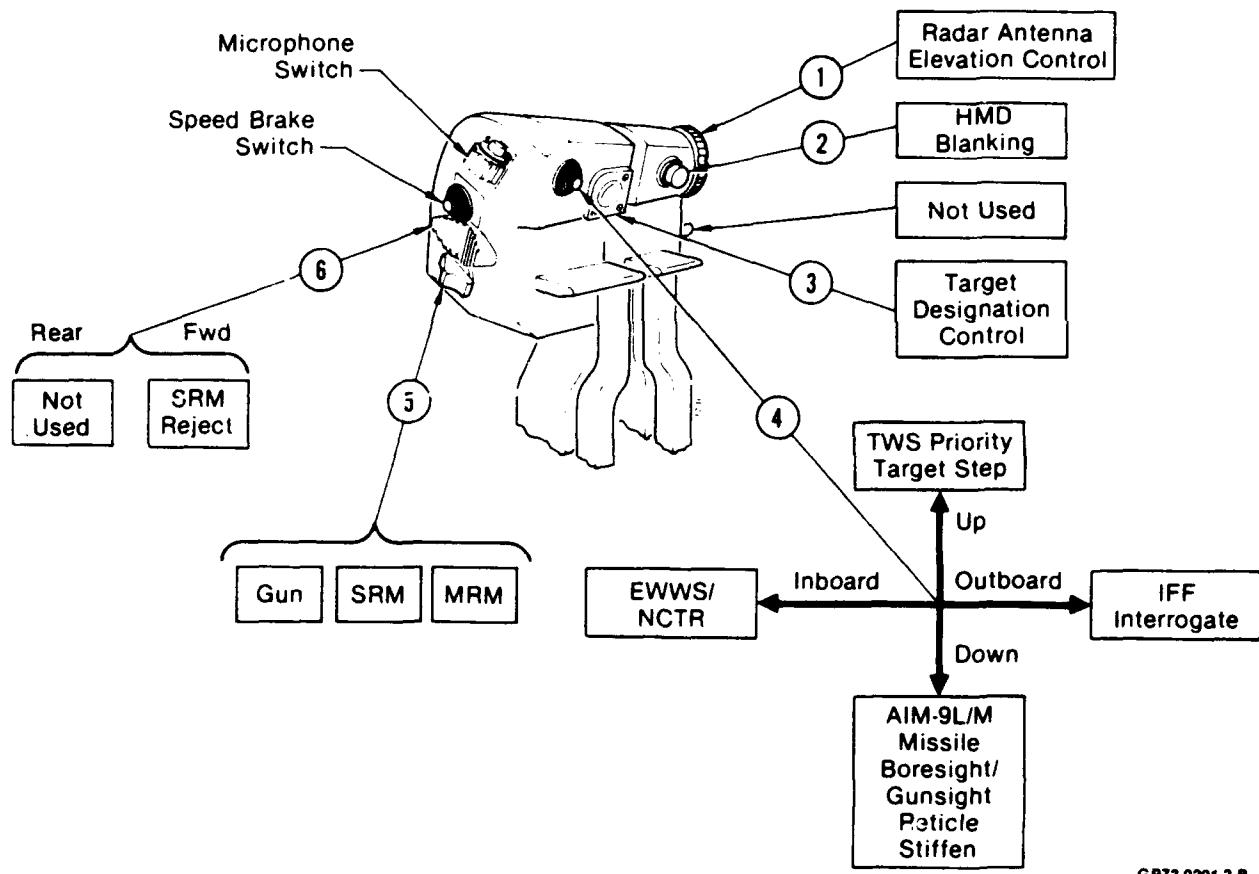
*Note: If press/release TDC and FORWARD within 2 sec, then:

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1 = RAM
2 = STT

Figure 3-2. HMD Auto Acquisition Switch Functions

3.2.2 Throttles - The switch functions on the throttles are depicted in Figure 3-3. Note the reticle stiffen and SRM reject switch locations were changed. The IFF interrogate button was a four-position switch with TWS priority target step, IFF interrogate, AIM-9 boresight/gun reticule stiffen and EWWS functions.



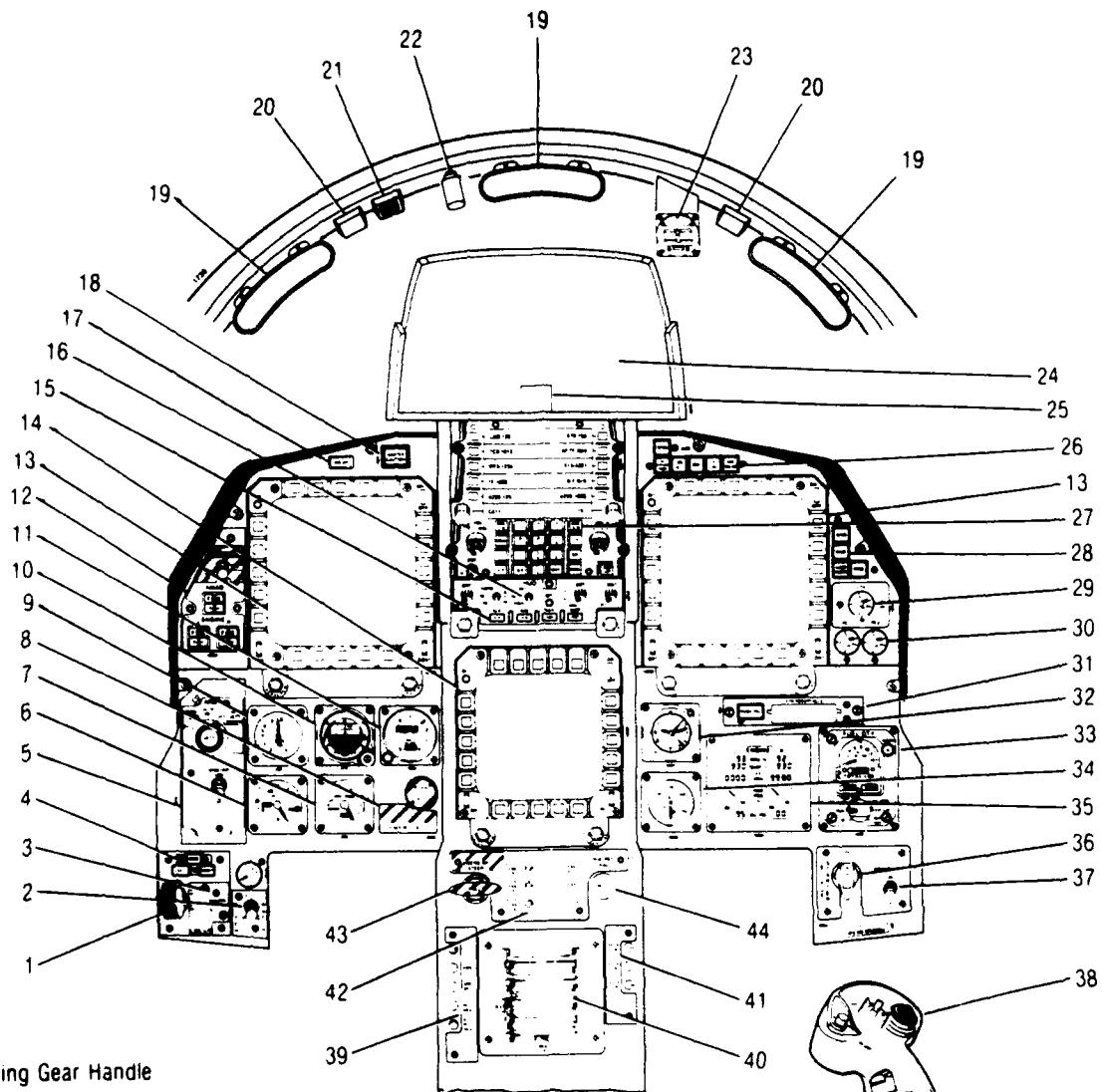
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Figure 3-3. Throttles Switchology

3.3 F-15E CREW STATION

In the VCSS simulation the F-15E was configured for aerial combat with radar and heat-seeking air-to-air missiles and a 20 mm gun. For the purpose of this simulation the F-15E VCSS crew station reflected the Multi Stage Improvement Program (MSIP) F-15C capabilities.

The forward crew station is depicted in Figure 3-4. Stick and throttle switchology were the same as the MSIP F-15C described earlier. VCSS HUD symbology was the same as the standard F-15 HUD. Radar symbols were presented on the left Multi Purpose Display (MPD) and TEWS symbols on the right MPD. The center color display displayed weapons data (simulated PACS display).

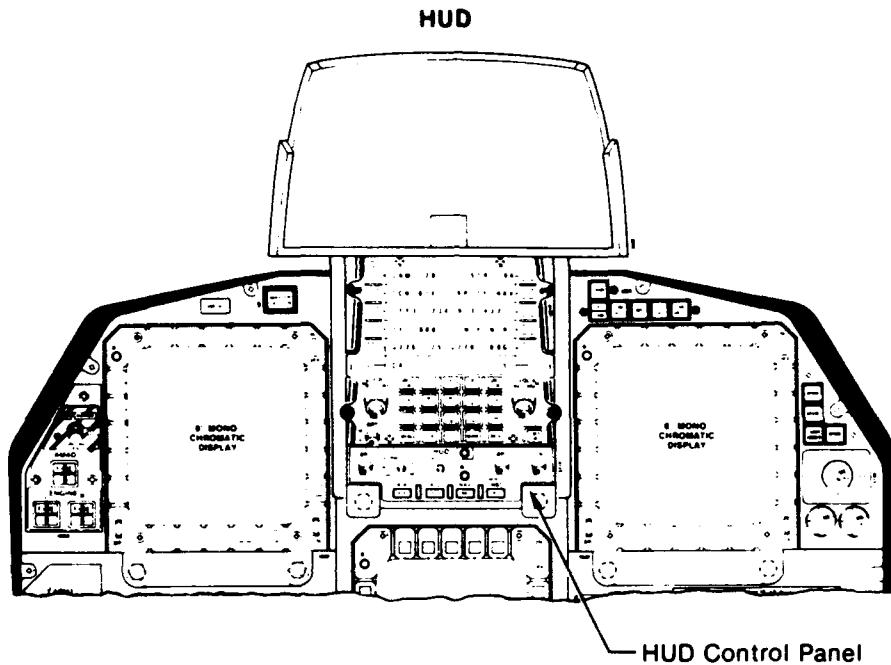


- 1. Landing Gear Handle
- 2. Pitch Ratio Select Switch and Indicator
- 3. Warning Tone Silence Select Switch
- 4. Landing Gear Position Lights
- 5. Armament Control Panel
- 6. Angle-of-Attack Indicator
- 7. Vertical Velocity Indicator
- 8. Emergency Jettison Select Switch
- 9. Standby Airspeed Indicator
- 10. Standby Altitude Indicator
- 11. Standby Altimeter
- 12. Fire Warning/Extinguishing Control Panel
- 13. Monochromatic Multipurpose Display
- 14. Multipurpose Color Display
- 15. Master Mode Select Switches
- 16. Head Up Display Control Panel
- 17. Emission Limit Caution Light
- 18. Master Caution Light
- 19. Rear View Mirror
- 20. Lock/Shoot Caution Lights
- 21. Air Refueling Ready Light
- 22. Chart Light
- 23. Standby Compass
- 24. Head Up Display Combiner
- 25. Head Up Display Camera Periscope
- 26. Warning Light Panel
- 27. Up-Front Control
- 28. Advisory Light Panel
- 29. Utility Hydraulic Pressure Indicator
- 30. Primary Hydraulic Pressure Indicator
- 31. Data Transfer Module Receptacle
- 32. Analog Clock
- 33. Fuel Quantity Indicator
- 34. Cabin Pressure Altimeter
- 35. Engine Monitor Display
- 36. Jet Fuel Starter Handle
- 37. Holding Brake Select Switch
- 38. Flight Control Stick Grip
- 39. Left Circuit Breaker Panel
- 40. ECS Variable Discharge Louver
- 41. Right Circuit Breaker Panel
- 42. Top Circuit Breaker Panel
- 43. Emergency Brake Steering Control
- 44. Rudder Pedal Adjustment Control

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Figure 3-4. F-15E Forward Crew Station Main Instrument Panel

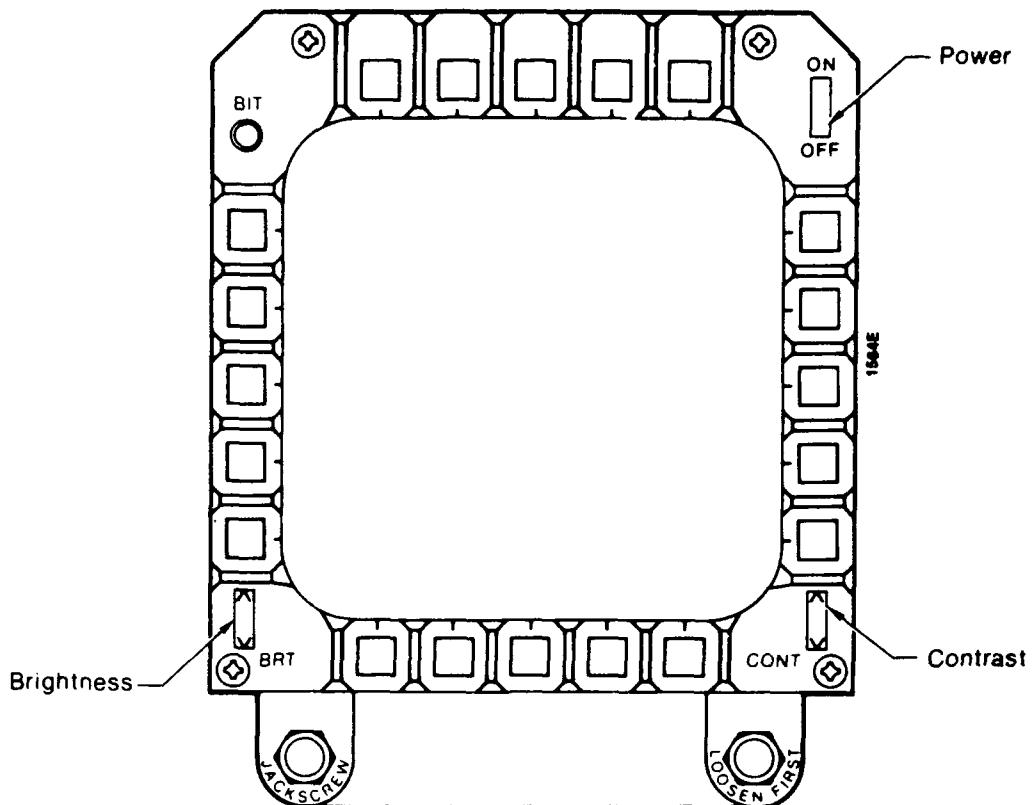
3.3.1 HUD Controls - The HUD controls were located directly below the UFC, see Figure 3-5. Power ON/OFF and symbol brightness were controlled by the far left knob. For this simulation the two knobs on the right were not used. The toggle switch on the left controlled symbol declutter.



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Figure 3-5. HUD Controls

3.3.2 Multipurpose Display Controls - Each of the three multipurpose displays had an "ON/OFF" toggle switch in the upper right corner. Brightness and Contrast rocker switches were in the lower left and right corners, respectively, see Figure 3-6.



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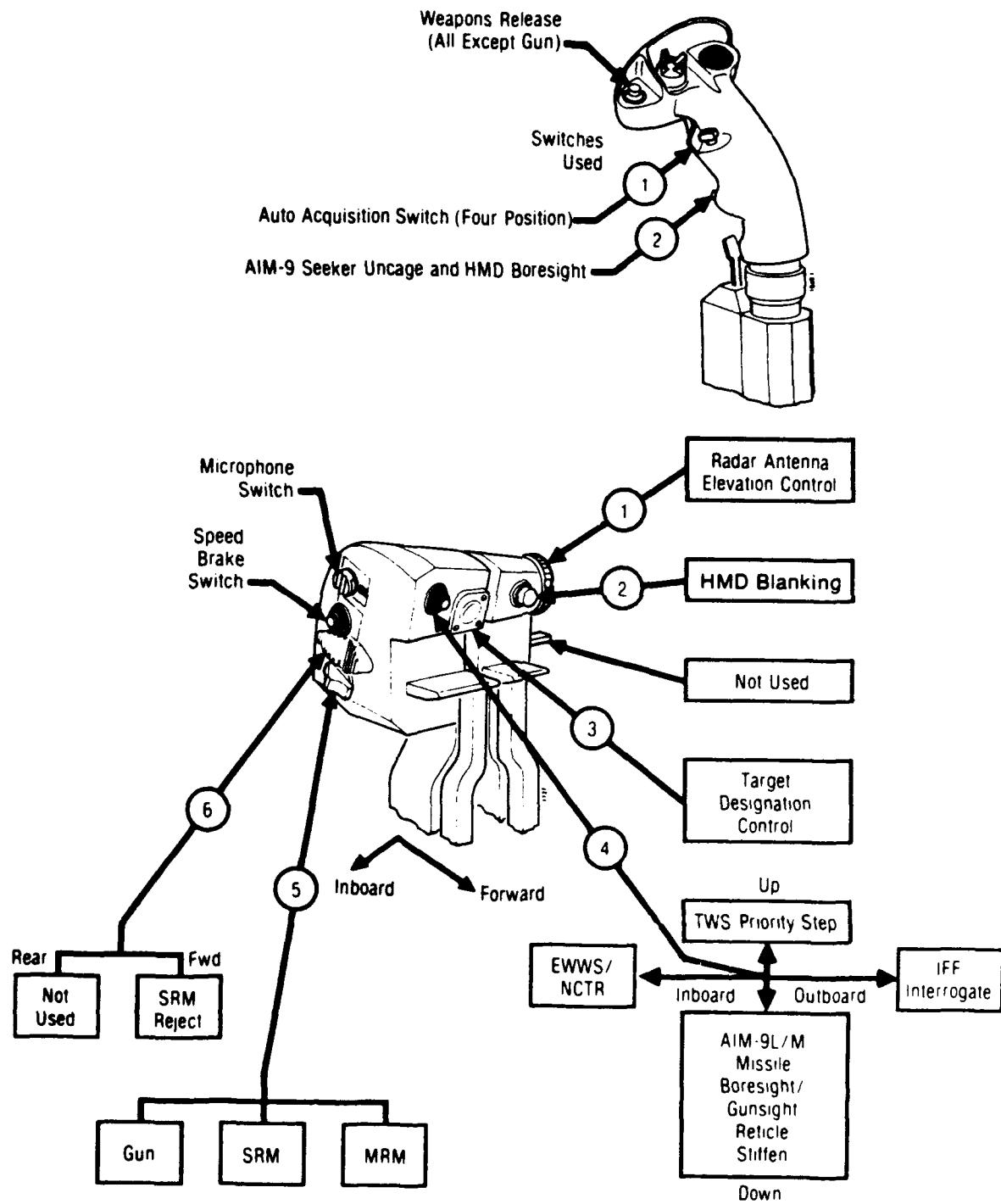
Figure 3-6. Multipurpose Display Controls

3.4 AGILE Eye Helmet Mounted Displays and Integration

This section provides a brief description of the Kaiser Agile Eye system, the controls required to operate it, and the changes made to integrate the helmet mounted display (HMD) into the F-15C avionics. The following summarizes these changes:

- o The forward and aft positions of the auto acquisition switch were redefined when the radar was in a search mode. The forward position of the switch provided Helmet Automatic Acquisition; the aft position had no assigned function.
- o The Supersearch, Boresight, and Vertical Scan auto acquisition modes were replaced by two helmet auto acquisition modes--Helmet Supersearch (HSS) and Helmet Boresight (HBST). Auto Gun Scan was available as a third auto acquisition mode and operates with no changes.
- o Operation of the AIM-9 L/M seeker (when not slaved to the radar) was changed. All operations that previously slaved the seeker to aircraft boresight slaved the seeker to the helmet Line of sight (LOS).
- o The HUD Symbol Reject switch controlled both HUD and HMD formats.
- o Certain symbols were removed from the HUD when the HMD was in use.

The F-15C MSIP stick grip and throttle control switches were as shown in Figure 3-7. Those used during operation of the HMD are indicated and are addressed in subsequent paragraphs. All other stick and throttle switches were unchanged in their operation.



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Figure 3-7. F-15C MSIP Stick Grip and Throttle Controls

3.4.1 Kaiser Agile Eye System - The Agile Eye helmet mounted display (HMD) systems used for this test were prototype versions to evaluate the concept of helmet mounted displays. Because they were prototypes, some aspects were less than ideal. Participants in the evaluation were asked to share their opinions on both good and bad points of this system. A summary of these comments is reported in the results section.

The Agile Eye system is composed of three major subsystems: the helmet itself, the head tracker and the display system which consists of a display processor and a display driver unit (DDU). These are illustrated in Figure 3-8 and described briefly below.

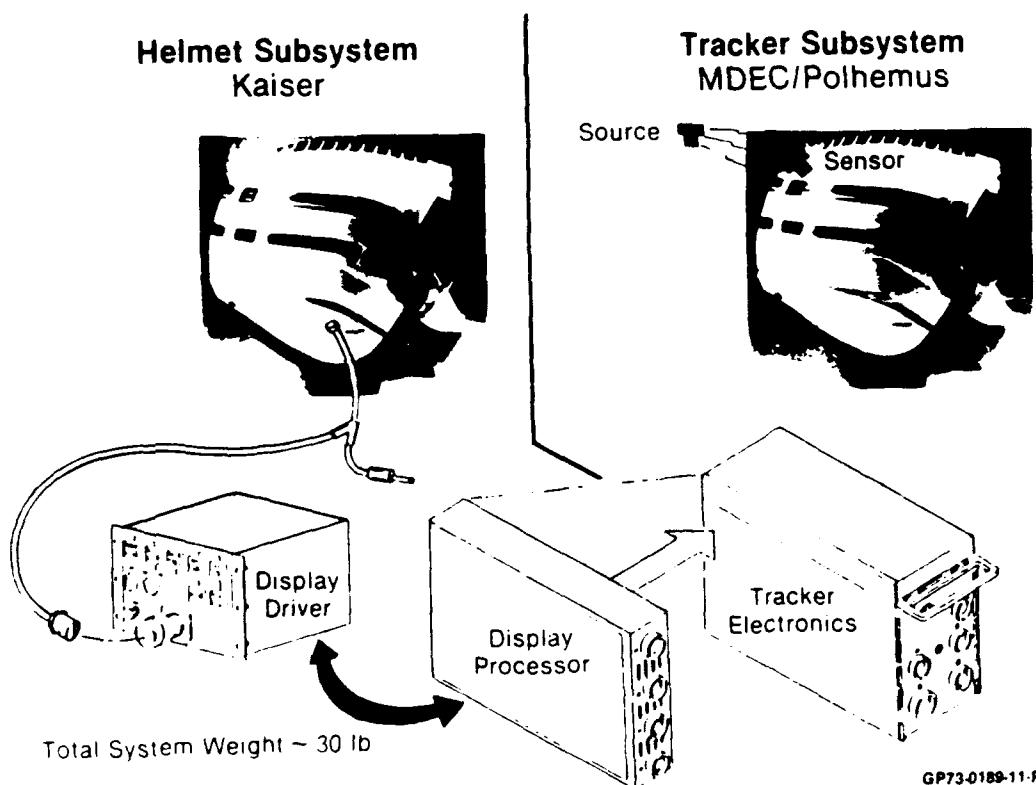


Figure 3-8. "Agile Eye" Helmet System

Agile Eye Helmet - The Agile Eye helmet was designed as a completely new flight helmet with a display integrated into the helmet. This avoids problems that previous helmet display systems have incurred by adding display elements to a standard flight helmet. The add-on approach has led to visibility, weight, and center of gravity (CG) problems which made the helmet undesirable (or even unacceptable) for use in flight.

The new design also improved three basic characteristics over the present USAF light weight flight helmet. The amount of aerodynamic lift produced by this helmet at high speed was cut in half. The weight was redistributed so that the overall CG of this helmet was closer to the natural CG of the human head than present helmets. The total weight (i.e., with tracker and display elements) was one-half pound lighter. This was done by using new components and Kevlar for the shell which provided the strength required for a flight helmet, but greatly reduced the weight.

Head Tracker - The Agile Eye system employs an electromagnetic tracking system manufactured by Polhemus Navigation Sciences, a subsidiary of McDonnell Douglas Electronics Company. A source, positioned above the pilot's head in the cockpit, radiates three orthogonal magnetic signals. In the simulator, the source was mounted on an arm attached to the ejection seat. In an aircraft, it could be mounted anywhere as long as it has a clear line of sight to the helmet.

The receiver was mounted in the top of the Agile Eye helmet. Changes in the orientation of the helmet relative to the source cause changes in the received signal. By comparing the transmitted and received signals, helmet position and orientation are determined. From these, line of sight (LOS) angles are computed. The display is then tailored for the LOS. Accuracy was not measured as part of this test. However, subjective assessment of the concept indicated that one-half degree would be sufficient for most flight operations. This is within the accuracy reported for the system when it has been properly installed and calibrated.

Helmet Display System - The display was provided by a half-inch diameter cathode ray tube (CRT), mounted inside the helmet on the right. The CRT image was transported to the helmet visor using fiber optics and mirrors. The visor was the final optical element and acted as the combining glass for the display, superimposing the display elements on the outside visual scene. This system produced a 12 degree field of view (FOV) display positioned at any LOS that the pilot could achieve through head movements.

The video signal for the helmet CRT was generated by a digital graphics processor. This signal is transmitted to the helmet at a low voltage level so that no spark would be produced by quick disconnect of the necessary electrical lines. A high voltage power supply was located within the helmet and converted the input video signal to the voltage levels necessary to drive the helmet CRT.

3.4.2 HMD Controls and Integration - The control panel for the HMS/D is shown in Figure 3-9. The only item used during the test was the brightness control which was set at the start of a session.

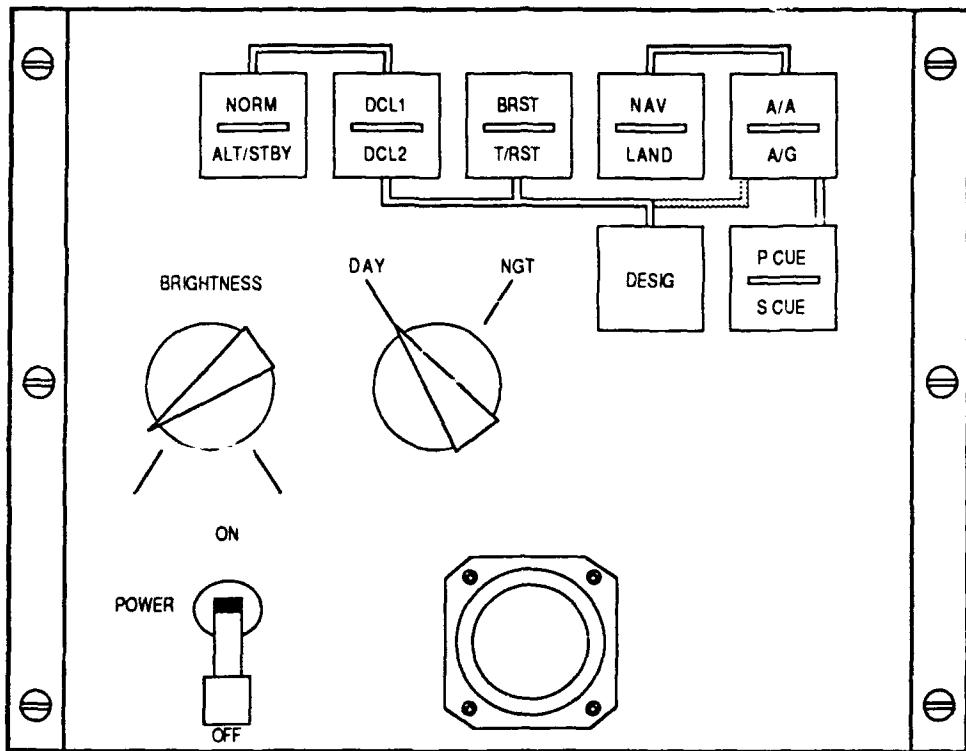


Figure 3-9. HMS/D Control Panel

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The HMS/D was integrated with the F-15 so that there was a minimum change in operational procedures for the pilots. A boresight procedure was added to ensure that the helmet sight was aligned with other aircraft systems.

The display formats used in this evaluation are summarized in Appendix A.

3.4.3 Compatibility With F-15 Avionics - The Agile Eye system can be easily integrated with the F-15 avionics. The prototype is currently configured to talk on a 1553A Bus. This military standard bus is available on post-MSIP (multi-staged improvement program) F-15s. The interface could be changed to work just as well with the H009 Bus which is on all F-15s.

The message traffic imposed on the bus is approximately 37 words. These pass data such as listed in Figure 3-10 between the central computer and the display processor tracker (DPT) at a 20 Hz rate.

- Display Symbol On/Off Flags
- Line-of-Sight Angles for Radar or Other Sensors and Corresponding Symbology (Display Two Simultaneously)
- Aircraft Parameters
 - Pitch/Pitch Rate — Mach
 - Roll/Roll Rate — Acceleration (Normal)
 - Heading — Airspeed
 - Yaw Rate — Altitude
 - Angle-of-Attack
- Message Window Locations and Alphanumerics in Each Window
- Helmet Parameters
 - Pitch — Line-of-Sight
 - Roll — Mode
 - Heading

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Figure 3-10. Data Parameters Passed Between the F-15 Avionics and the Agile Eye DPT

The DPT is the interface to the Agile Eye through its mux bus connection as seen in Figure 3-11. The DDU (display driver unit) is mounted in the cockpit next to the standard existing communications and oxygen connectors which continue to serve their current functions. The display functions are implemented by plugging the umbilical cord quick disconnect into the DDU.

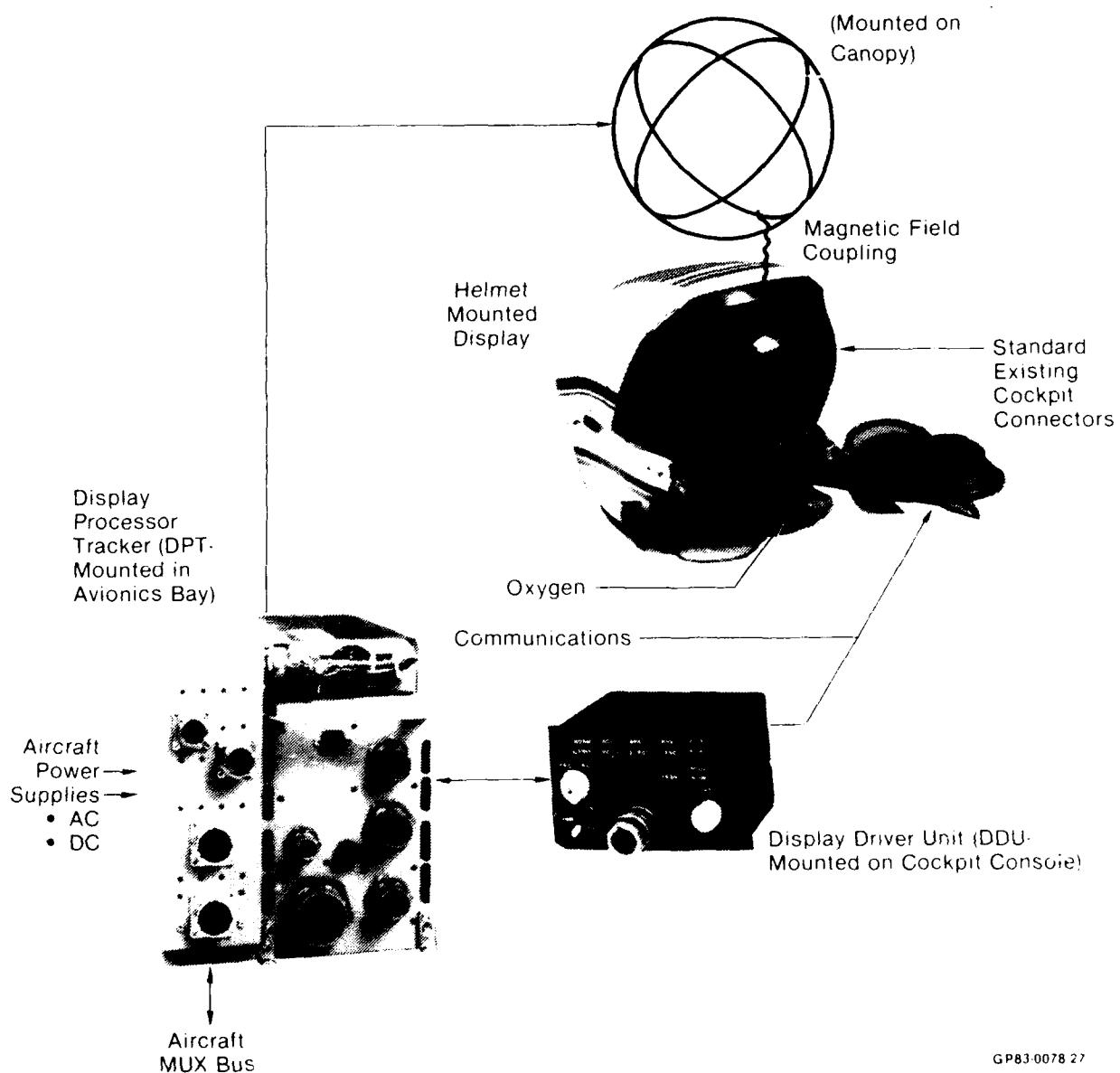


Figure 3-11. Component Interconnects for the Agile Eye Flight Test Prototype System

There are several possibilities for connecting to the F-15 avionics system as shown in Figure 3-12. The first is to use the 1553 Bus, if available on the aircraft, and the existing design of the DPT. The second is to redesign the DPT bus interface to work with the H009 Bus. The third is to redesign the DPT and the signal data processor (SDP) to be collocated and interface with the H009. With redesign of the SDP, better than 50 percent of the volume could be freed. There are 16 cards now in the SDP. These could be reduced to seven with today's technology and drive a stroke only HUD. The vacated card slots would probably provide sufficient volume for a redesigned DPT.

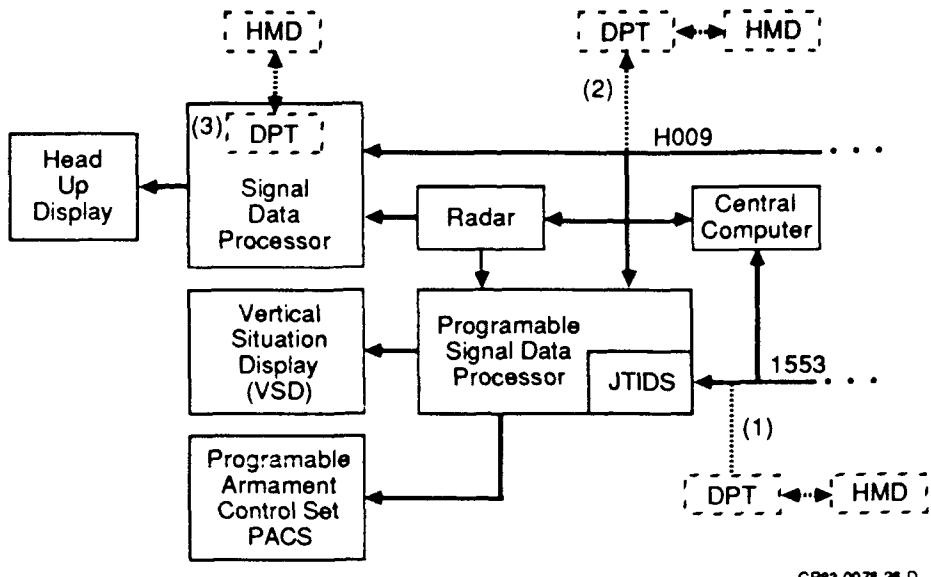


Figure 3-12. Simplified Block Diagram of F-15/Agile Eye Interface Options

3.5 MICS CREW STATIONS

The Manned Interactive Control Stations (MICS) were used by the red team pilots. The MICS, as depicted in Figure 3-13 consist of a CRT display screen, a control console, a stick grip, and a throttle quadrant. The switches located on the control console and the throttle and stick grips control the aircraft's weapons and avionics in a manner similar to the F-15 crew stations, resulting in a fully capable aircraft. The stick grip and throttle controls provide sufficient flight control and propulsion control for the aircraft.

The CRT display screen in front of the MICS pilot shows scaled versions of the BVR (beyond visual range) displays available on the displays in the crew stations. BVR information available to the pilot of either a domed crew station, MACS, or a MICS was similar. An additional display was available to the MICS pilot that represents the relative position and attitude of other aircraft within visual range throughout the visual envelope. The same "out-the-window" information was given in both stations but in different formats. The aerodynamic performance of an aircraft controlled from a MICS is the same as if the control were from a MACS.

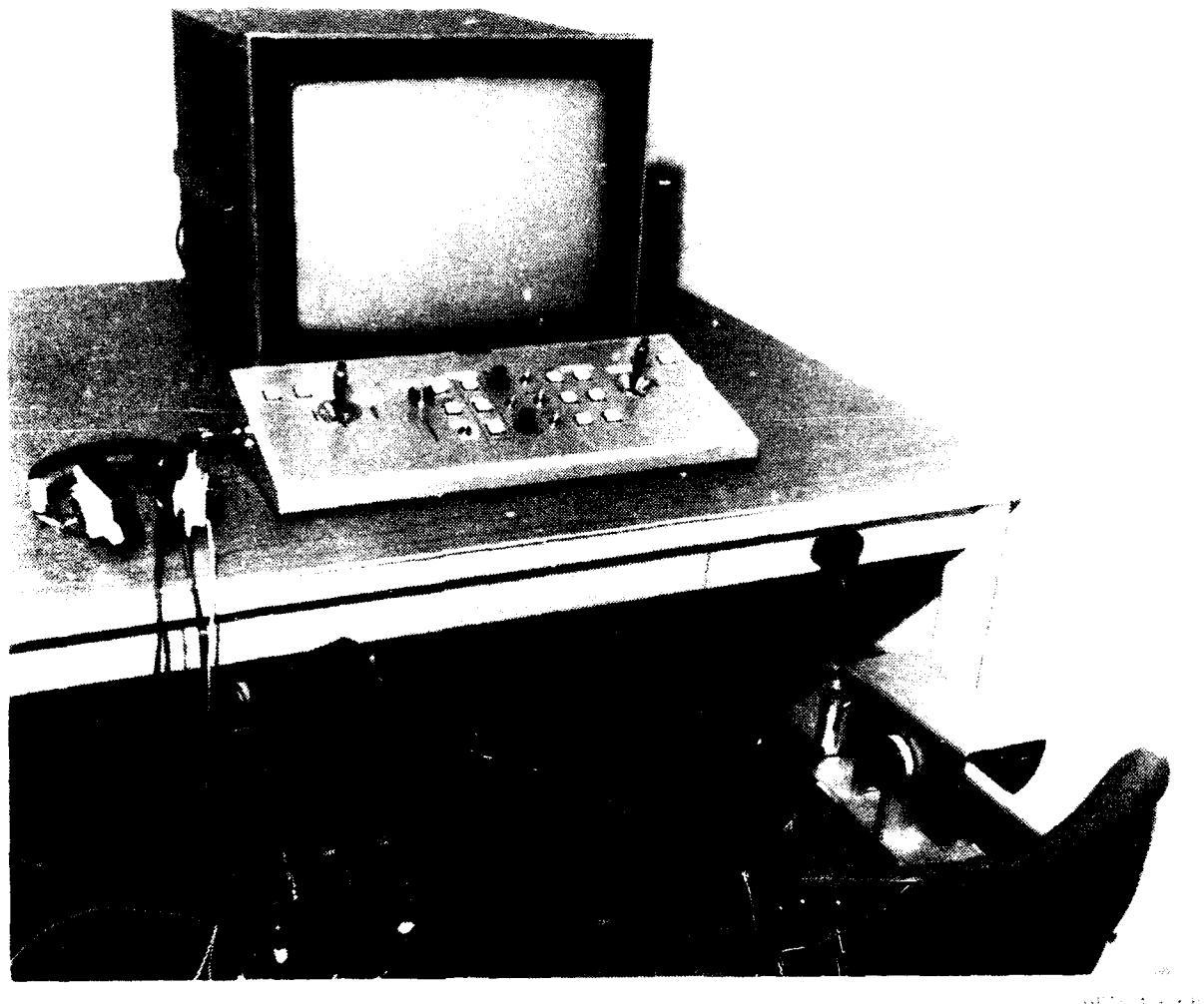


Figure 3-13. MICS Components

4.0 TEST DESCRIPTION

The purpose of the simulation was to demonstrate and measure the utility of a HMS/D in air-to-air combat. Four operational, F-15 C/D, TAC pilots and four Aggressor pilots flew the missions along with digital aircraft embedded in the simulation. Two F-15 and two aggressor pilots flew simultaneously in one week of testing. This was followed by a second week of testing with the other four pilots.

The objective of this test was to demonstrate and evaluate the utility of a helmet mounted display (HMD) in air combat. This was accomplished by simulating various air combat situations, collecting pilot comments, and comparing results when pilots have the HMD ("Helmet On") with results in a conventional cockpit ("Helmet Off"). The test scenarios included enemy fighters, enemy bombers, and friendly aircraft. Both offensive and defensive missions were examined. The enemy fighters were both digital and manned by "aggressor pilots" flying from MICSSs.

During the test, multiple runs up to 15 minutes each were performed. Each run had a different set of initial conditions; i.e., the other aircraft differed in type, starting position, and total numbers. Each set of initial conditions was used twice - once with the HMD off, and once with the HMD on--as much as practical. Scheduling limitations prevented collecting a full factorial set of data.

When the HMD was off, the simulators functioned as normal F-15C MSIP aircraft. When the HMD was on, the systems were changed to the integrated HMD/S configuration.

The basic tasks of the F-15 pilots during the test were to operate as a flight, destroy enemy aircraft, avoid attacking friendly aircraft, and successfully defend against enemy attacks. Toward this end, they were instructed to employ standard USAF two-ship air combat tactics.

Subjective workload data were collected from both F-15 and Aggressor pilots. Objective data collected included kills and weapons employment data. The experimental design described provided maximum, control of learning and practice effects within the constraints of time and numbers of missions.

4.1 TEST EQUIPMENT

The test was performed in McDonnell Aircraft Company's Manned Air Combat Simulators (MACS). MACS-IV, which is configured as an F-15C, and MACS-V, which is configured as an F-15E were used. The F-15E cockpit was programmed so that the basic avionics operated as an F-15C. Although the cockpit appearance is different, the left CRT was used to display the F-15 VSD and the right CRT for the TAWS display. The stick and throttle switches were identical in both cockpits and provided F-15C functions.

Each cockpit is built on a platform that sits in the middle of a 40 foot diameter sphere, or "dome". During operation, computer graphics are used to project ground, sky, and other aircraft onto the surface of the dome. This provides full vision capabilities to the pilot in addition to the cockpit displays. The overall visual effect might give a sensation of motion; however, the cockpit and platform are stationary.

The following limitations were present during this test. First, the amount of navigation that could be performed was limited. The Dynamic Earth/Sky system was used to provide the out-the-window background visual scene. This system provides a horizon and a generic ground pattern. It provides excellent cues for BFM (Basic Fighter Maneuvering), but cannot be used to navigate. The TACAN or INS systems were not simulated. However, Nav destinations were displayed on the VSD display. Four destinations (B, 1, 2, and 3) were programmed for use during the test to provide indications of FEBA location and the position of the airfield. Their locations are shown in the figures describing Test Scenarios.

The targets were not displayed until they were within 2.5 NM of an aircraft. Therefore, the best eyes in the world did not appreciably help visual contact. While fighting, if a pilot exceeded 4 Gs for 30 seconds, he experienced "grayout" as the entire dome was turned off. A sliding scale of time vs. Gs caused the grayout function to occur sooner if more Gs were pulled. Recovery was not instantaneous, and the longer he grayed out, the longer it took after unloading to "recover". M-1 and L-1 maneuvers did not help no matter how well they were performed.

Figure 4-1 illustrates the interconnection of the Agile Eye with the simulation facility. The IMI graphics generator drove the Agile Eye helmet display. The IMI is a stroke graphics device capable of refresh rates up to 100 hz. The Polhemus head tracker communicated with the SEL 32/9780 host processor through the real-time I/O buffer. This buffer was essentially a standard serial interface operating at high speed.

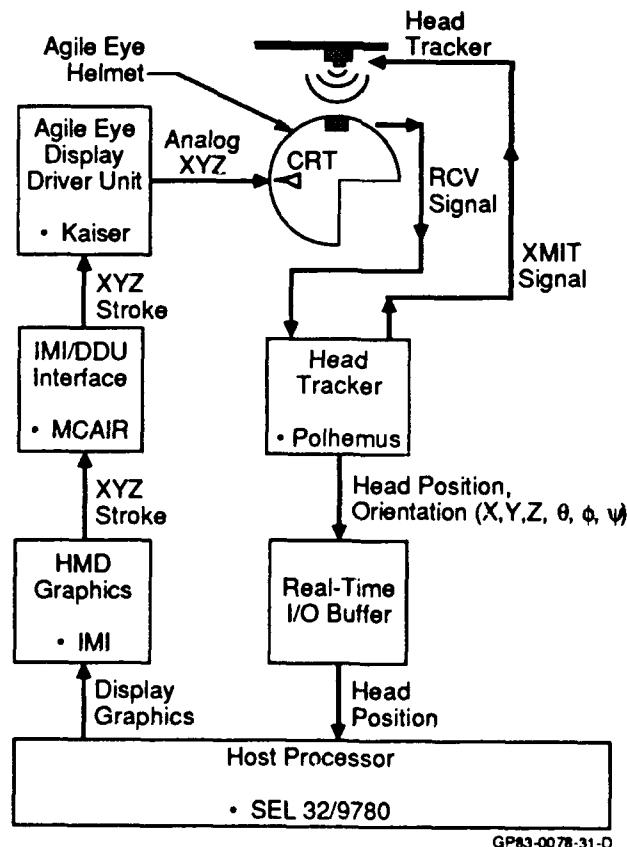


Figure 4-1. F-15 SIM/Agile Eye Integration

4.2 PILOT PARTICIPANTS

The participating aircraft were flown by F-15 pilots, F-5 Aggressor pilots, and digital pilots.

4.2.1 F-15 Pilots - There were two F-15 pilots involved in all test runs. One pilot flew MACS-IV, which has an F-15C MSIP cockpit. The other pilot flew MACS-V which has an F-15E cockpit programmed to function as an F-15C MSIP. The F-15 pilots performed as a two-ship flight of Blue fighters.

4.2.2 F-5 Aggressor Pilots - Two F-5 Aggressor pilots from the 57 FWW, Nellis AFB, participated in all runs. They operated MICS stations. The Aggressor pilots acted as "manned" Red fighters and simulated either MiG-23 Floggers or MiG-29 Fulcrums. Their objective was to attack and kill the F-15s. They were armed with semi-active radar missiles, infrared missiles, and guns.

4.2.3 Digital Pilots - Up to six digital aircraft were added to each test run. These aircraft were under the control of the host simulation computer and were used for three different purposes:

- o Red Fighters - They supplement the Aggressors. They fly a route until they are within detection range of an F-15. The computer then takes whatever actions are necessary to maneuver to launch position for an attack on the closest F-15. They were used to simulate MiG-21 Fishbeds and were armed with infrared missiles and guns.
- o Red Bombers - They fly a canned route to a target. In this mode, they do not attack the F-15s, but they did attack a ground target. They also tried to evade attacks by the F-15s. Red bombers were simulated MiG-23 strike aircraft.
- o Other Blue Aircraft - They fly a canned route and can be thought of as other friendly forces (e.g. strike aircraft, recce, etc.). These were used to inject the identification problem into the test.

The digital pilots did not participate in the 2v2 and 1v1v1v1 scenarios i.e., those that began WVR. At least two digital pilots were present in all other scenarios. The specific number of digital pilots and the type aircraft they simulate varied on each test run. There were runs with six present, and they simulated all three aircraft types.

4.3 PROCEDURE

The pilots were tested and debriefed. These basic tasks were interleaved to make the best use of time and the simulation facility.

4.3.1 General Procedure Training - The pilots were given an introduction to the Visually Coupled Systems Simulation study. Personnel background data, and data for developing a workload assessment scale were collected on the first day, and training was started.

Training was conducted in stages. The first stage was a "ground school" segment, followed by a static segment in the cockpit and finally a dynamic segment. An instructor was present during all training segments. Training included:

- 1) Aircraft flight characteristics and crew station familiarization
- 2) Helmet mounted sight operation and display formats
- 3) Weapon characteristics and employment
- 4) Threat characteristics

After completing training, tests for record were run.

Informal debriefings were held at the end of each day. A final, more formal, debriefing was held at the conclusion of testing.

4.3.2 Test Runs - Crews reported in flight suit, and boots.

The pilots were given a premission brief. A brief review was given by the instructor of the configuration being tested, ROEs, and route.

The pilot entered the cockpit, and the test conductor reviewed the test run parameters.

Initial conditions were set. The pilot was alerted, and the test run was started.

During the run the test conductor monitored the flight profile, displays, threats and test parameters from a remote control station.

Each of the four F-15 pilots flew the 2v4 and 2v8 combat missions at least four times without the HMS/D and four times with it. F-15 pilots alternated between MACS IV and MACS V according to their preference. A total of 32 runs were allotted to 2v4 and 2v8 offensive and defensive missions. As many 2v2 and 1v1v1v1 missions were conducted as time permitted.

A run that began BVR (2v4 or 2v8) required approximately 10 minutes. A run that began WVR (2v2 or 1v1v1v1) required approximately 5 minutes. Four versions of each BVR scenario were prepared. A different order of the four version was generated by Latin square for each group of pilots and each offensive or defensive condition. The scenarios are described below. The orders and test schedules are shown in Figures 4-2 and 4-3.

	Monday	Tuesday	Wednesday	Thursday	Friday
0800		Briefings 0800-1100	2 v 4 DCA Helmet On A,B,D,C	2 v 4 OCA Helmet On D,A,C,B	
0900			2 v 4 DCA Helmet Off B,C,A,D	2 v 8 DCA Helmet Off E,F,H,G	2 v 8 OCA Helmet On G,H,E,F
1000			2 v 4 OCA Helmet Off C,D,B,A	2 v 8 DCA Helmet On F,G,E,H	2 v 8 OCA Helmet Off H,E,F,G
1100		Helmet Fit Familiariza- tion 1100-1500	2v2/Off 2v2/On 1v1v1v1/Off 1v1v1v1/On	2 v 2/On 2 v 2/Off	1v1v1v1/Off 1v1v1v1/On 2v2/On 2v2/Off
1200					Final Debrief 1200-1400
1300			Daily Debrief 1300-1400	Daily Debrief 1300-1400	
1400					
1500		Daily Debrief 1500-1600			
1600					
1700					

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Figure 4-2. Week One Schedules and Order of Initial Conditions

	Monday	Tuesday	Wednesday	Thursday	Friday
0800		Briefings 0800-1130	2 v 4 OCA Helmet Off B,C,A,D	2 v 4 DCA Helmet On A,B,D,C	2 v 8 DCA Helmet Off H,E,G,F
0900			2 v 4 OCA Helmet On C,D,B,A	2 v 8 OCA Helmet On F,G,E,H	2 v 8 DCA Helmet On E,H,F,G
1000			2 v 4 DCA Helmet On D,A,C,B	2 v 8 OCA Helmet Off G,H,F,E	1v1v1v1/On 1v1v1v1/Off 1v1v1v1/Off 1v1v1v1/On
1100			1v1v1v1/On 2v2/On 1v1v1v1/Off 2v2/Off 1v1v1v1/Off 2v2/Off 1v1v1v1/On 2v2/On	2v2/Off 1v1v1v1/On 2v2/On 1v1v1v1/On 2v2/On 1v1v1v1/On 2v2/Off 1v1v1v1/On	2v2/Off 1v1v1v1/On 2v2/On 1v1v1v1/Off 1v1v1v1/Off 1v1v1v1/On
1200		Helmet Fit Familiariza- tion 1230-1600			
1300				Daily Debrief 1300-1400	Final Debrief 1300-1500
1400					
1500			Daily Debrief 1400-1500		
1600		Daily Debrief 1600-1700			
1700					

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Figure 4-3. Week Two Schedules and Order of Initial Conditions

Simulator test time was approximately twelve hours per pilot. The combination of approximately twelve hours of testing per pilot and four hours of familiarization results in almost twenty hours of simulator time per pilot. For the TAC demonstration, a total of approximately 40 hours was spent in the simulator.

4.4 TEST SCENARIOS

Three basic scenarios were used: an Air Base Defense Scenario, a Fighter Sweep Scenario, and Visual Setups. The Base Defense and Sweep scenarios were set in the context of actual missions and involved up to ten aircraft (counting the F-15s). The visual setups involved only four aircraft, were less complex, and were task rather than mission oriented.

4.4.1 Air Base Defense Scenario - The basic setup for this mission is shown in Figure 4-4. At the start of each run, the F-15 aircraft were positioned 6000 ft. apart, line abreast, at 15,000 ft. MSL, Mach 0.8, heading 090°. The starting position was 10 NM east of the airfield that must be defended and 10 NM west of the assigned CAP point. The FEBA was simulated by a north-south line 30 NM east of the F-15s. The 1, 2, 3, and B points represent Nav destinations. These were displayed on the VSD when they were within 60° of the nose.

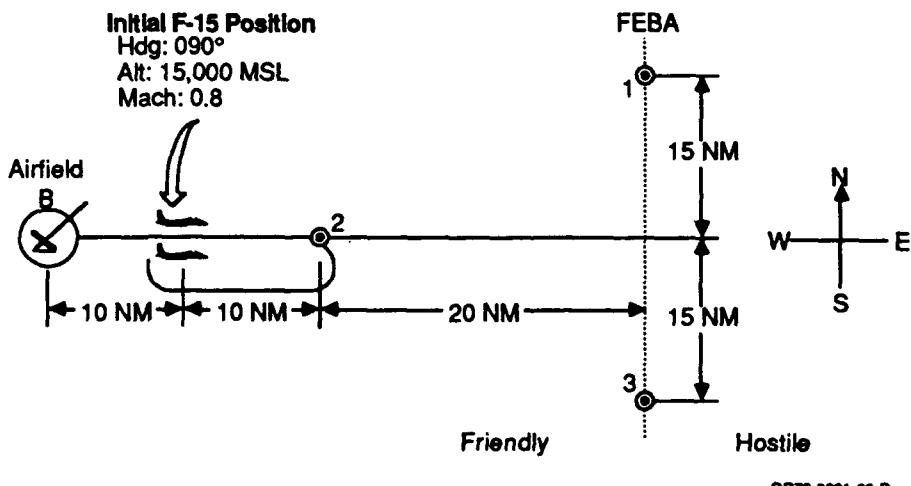


Figure 4-4. Air Base Defense Setup

At the start of each run, the F-15s encountered a different mix of targets. The primary objective was to stop any bombers; however, there were at least two enemy fighters in every run, and the F-15s had to defend themselves while searching for the bombers. Other blue aircraft were also present and were not to be attacked. Typical initial conditions are shown in Figure 4-5.

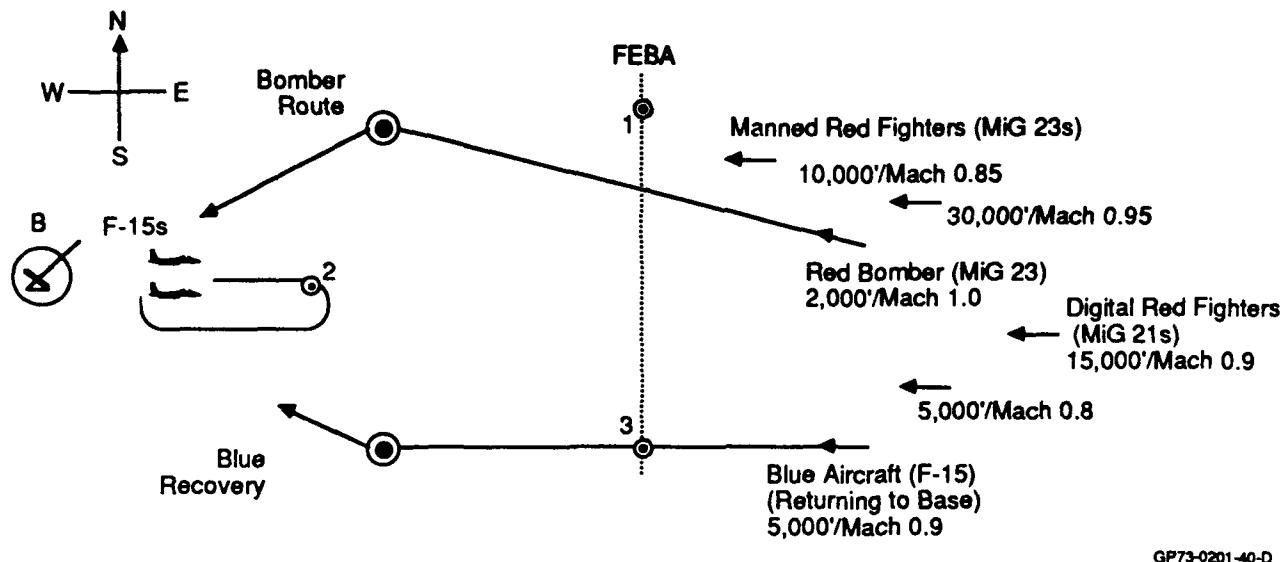


Figure 4-5. Typical Initial Conditions Air Base Defense Scenario

During the Air Base Defense scenarios, the F-15s received GCI assistance, simulated by test operators, in locating and keeping track of all other aircraft. The AAI was available and could be used to identify friendly aircraft.

Kill removal applied to red and blue team participants. Red bombers attempted egress to the east after reaching their targets. Other blue aircraft were removed upon reaching the airfield.

Eight different setups were used for this scenario. Each setup involved a different number of aircraft and different ratios of aircraft type. Each setup was performed twice: once with the HMD and once without the HMD. A total of 16 Air Base Defense test runs were performed.

4.4.2 Fighter Sweep Scenario - The basic setup for this mission is shown in Figure 4-6. At the start of each run, the F-15 aircraft were positioned 6000 ft. apart, line abreast, at 15,000 ft. MSL, Mach 0.8, heading 090°. The starting position was 10 NM west of the FEBA, which is again simulated by a north-south line. The numbers shown represent Nav destinations. These are displayed on the VSD when they are within 60° of the nose.

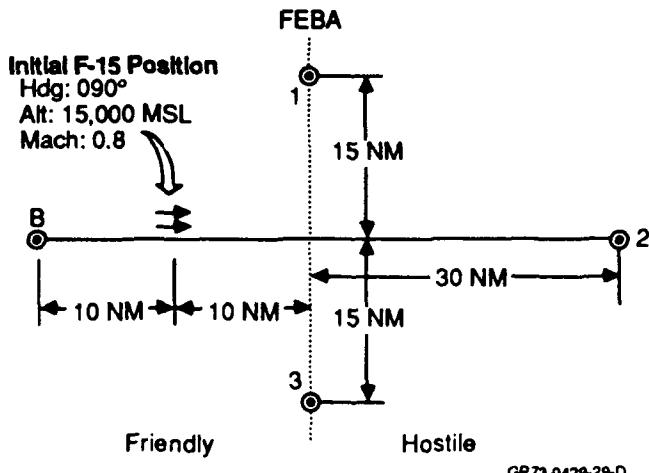


Figure 4-6. Fighter Sweep Set Up

At the start of each run, the F-15s encountered a different mix of targets. The primary objective was to penetrate enemy territory, destroy as many enemy aircraft as possible while avoiding attack, and return to friendly territory. There were at least two enemy fighters in every run plus enemy bombers. Other blue aircraft were present and these were not to be attacked. Typical initial conditions are shown in Figure 4-7.

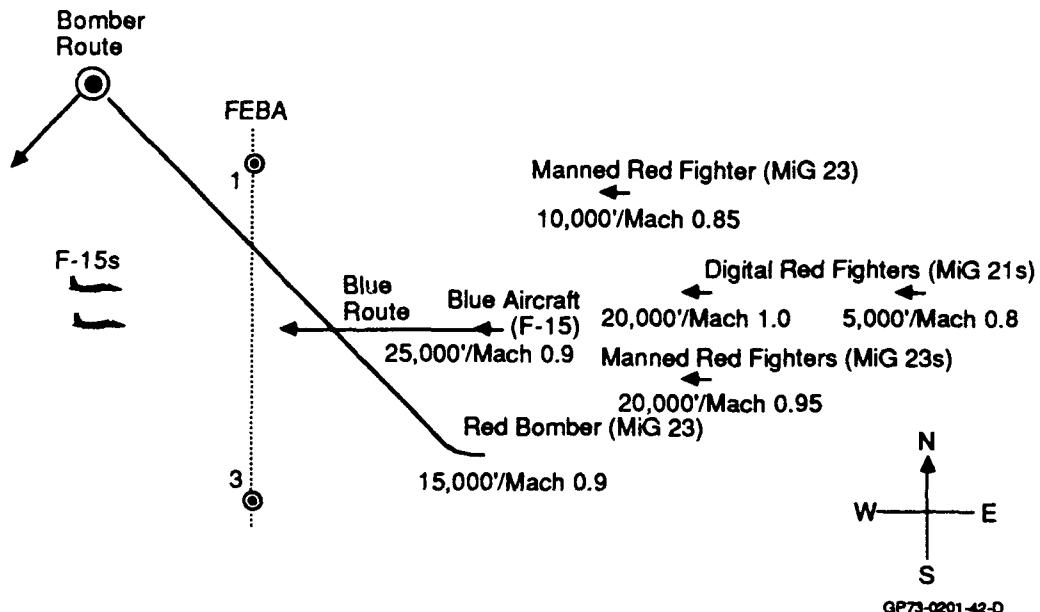


Figure 4-7. Typical Initial Conditions Fighter Sweep Scenario

During the Fighter Sweep scenarios, no GCI was available to Blue but was given to Red. The AAI was available to identify friendly aircraft. All kill removal rules for the Air Base Defense scenarios were used in the Fighter Sweep scenarios and Red Aircraft that crossed the FEBA heading west were removed when they were 10 NM West of the FEBA.

Eight different setups were used for this scenario. Each setup involves a different number of aircraft and different ratios of aircraft type. Each setup was performed twice: once with the HMD and once without the HMD. A total of 16 Fighter Sweep test runs were performed.

4.4.3 Visual Setups - A 1v1v1v1 setup and a 2v2 setup were used. Only F-15 pilots and F-5 pilots participated in these runs. The primary purpose of these runs was to force the pilots into unprepared, quick reaction situations and determine if the HMD helps. An example of this might be a bugout following a visual turning fight when the pilot has not had an opportunity to establish radar search and is primarily in a visual mode.

The 1v1v1v1 setup is shown in Figure 4-8. The four pilots were placed on the circumference of a 5 NM circle at different altitudes. All pilots had to maintain the starting altitude until crossing the center of the circle. When the last aircraft crossed the center of the circle, the test director called "fight's on" and the pilots could maneuver. Each participant could engage any other aircraft. Killed aircraft were removed from the run. The objective was to be the sole remaining participant.

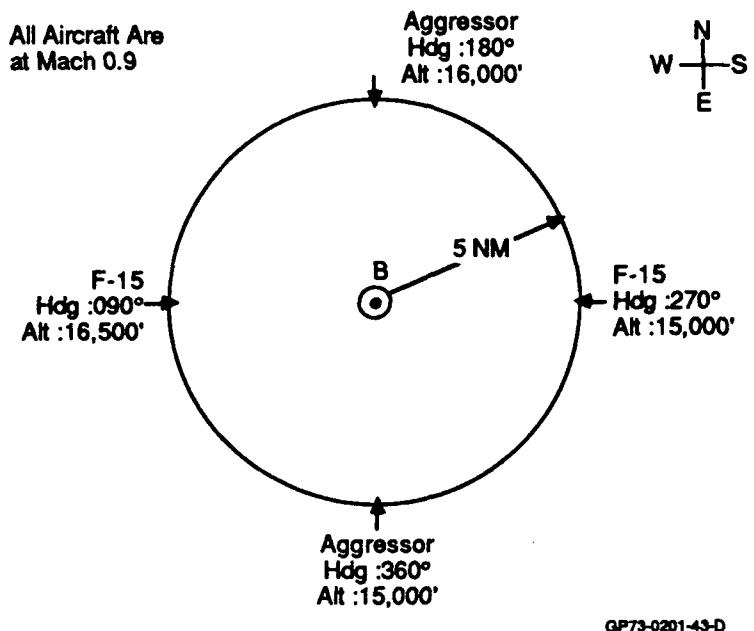


Figure 4-8. 1v1v1v1 Set Up

The 2v2 setup is shown in Figure 4-9. In this mission, the two F-15 pilots exercised mutual support and worked together to kill the two Red fighters. The Red fighters could maneuver independently or together to achieve an advantage on the F-15s. Killed aircraft from either side were removed from the run. The objective was for the F-15s to defeat both MiGs without losses.

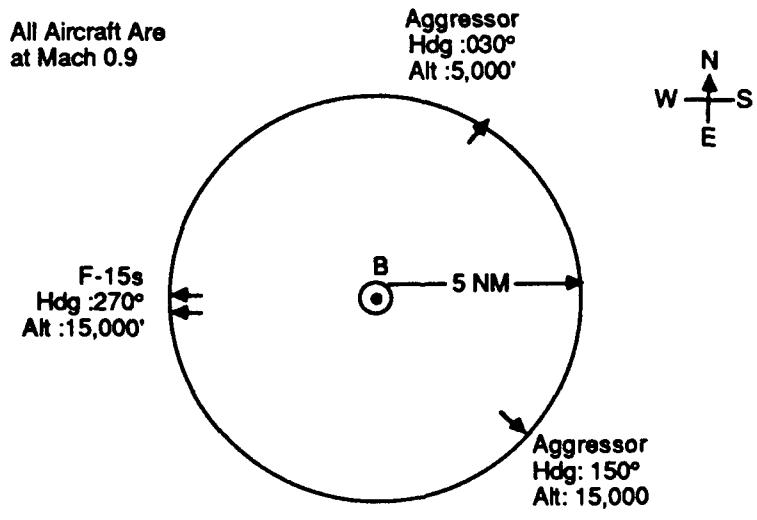


Figure 4-9. 2v2 Set Up

4.5 RULES OF ENGAGEMENT (ROE)

4.5.1 Air Base Defense ROE - These are the ROE followed during the test runs.

- o All targets must be identified as hostile prior to weapon release. Identification may be accomplished by AAI, GCI, or visually.
- o Aircraft will be removed from the scenario whenever any of the following conditions occur:
 - Any aircraft killed is removed.
 - Other Blue aircraft that reach the airfield are removed.
- o The Air Base Defense scenario will terminate when all Red aircraft have been removed or at the expiration of 15 minutes from the start of the run, whichever comes first.

4.5.2 Fighter Sweep ROE

- o All targets must be identified as hostile prior to weapon release. Identification may be accomplished by AAI, GCI, or visually.
- o Aircraft will be removed from the scenario whenever any of the following conditions occur:
 - Any aircraft killed is removed.
 - Any Red aircraft that cross the FEBA are removed 10 NM west of the FEBA.
 - Other Blue aircraft that reach the airfield are removed.
- o The Fighter Sweep scenario will terminate when all Red aircraft have been removed, at the expiration of 15 minutes from the start of the run, or after the F-15s reach a point 15 NM west of the FEBA, whichever comes first.

4.5.3 1v1v1 Visual Setup ROE

- o Aircraft may not depart their assigned altitude until crossing the center of the circle.
- o Aircraft may not engage prior to the "fight's on" call.
- o After "fight's on" each participant may attack any of the other three aircraft.
- o Aircraft are removed from the scenario when they are killed (Both Blue and Red).
- o This scenario will terminate whenever any of the following conditions occur:
 - Both F-15s have been removed.
 - Only one aircraft remains.
 - Time limit of 15 minutes is reached.

4.5.4 2v2 Visual Setup ROE

- o Red fighters will only engage F-15s, and F-15s will only engage Red fighters.
- o Aircraft are removed from the scenario when they are killed (Both Blue and Red).
- o This scenario will terminate whenever any of the following conditions occur:
 - Both F-15s have been removed.
 - Both Red fighters have been removed.
 - Time limit of 15 minutes is reached.

5.0 RESULTS

A total of 101 runs were successfully completed. Of the 101 total runs, 27 were 1v1v1v1 or 2v2 "visual scenarios", and 64 2v4 and 2v8 scenarios. While the 1v1v1v1 and 2v2 scenarios could and often did evolve into BVR engagements and the 2v4 and 2v8 scenarios could become visual engagements, the smaller scenarios were more likely to include within visual range combat during the initial phase. The larger scenarios were presented equally often to both pilot groups because planned presentations of the visual scenarios were sacrificed to maintain the test plan for the larger scenarios, they could not be conducted equally often for both groups or at regular intervals. Results of both scenario types will be discussed following a summary of the types of data collected.

5.1 VARIABLES EVALUATED

The variables analyzed were chosen on the basis of three factors: availability, validity as a measure of tactical worth, and relationship to some aspect of HMD use. Availability refers to the ability to collect data during the simulation, either from the simulation computers, or from the pilots themselves, as in the case of the SWAT (Subjective Workload Assessment Technique) workload measure. Assessing the usefulness of the HMS/D in the tactical environment was a primary objective of the test, and variables with high intrinsic validity as indicators of tactical worth (i.e., numbers of kills and losses) were included. Other variables were included in the hope they would provide information as to how the HMS/D was used and how it affected the overall conduct of the mission at a more detailed level.

The 12 variables chosen are shown in Figure 5-1. The number of red and blue kills were the measures of tactical worth chosen for this analysis. The Red Kills variable reflected losses of both manned Blue aircraft to either manned or digital Red aircraft. Blue losses due to attacks by other Blue aircraft were excluded. The Blue Kills variables included all downed Red aircraft, regardless of whether they were piloted MICS stations, Red fighters or Red Bombers. The effectiveness of short-range weapons was separately assessed by the AIM-9 Launches and AIM-9 Kills variables.

Blue Kills
Red Kills
Blue SWAT
Red SWAT
LOS/HUD
LOS/45
Supersearch
Boresight
First Time
First Range
AIM-9 Kills
AIM-9 Launches

GP730429-25-A

Figure 5-1. Variables Analyzed

Tactical utility, as reflected in increased kills and decreased losses, is a primary goal for the HMS/D. However, it is also desirable that this goal be achieved without the increased workload that might result from adding a new device to the cockpit. SWAT data were collected from the Blue pilots to assess the effect of the HMS/D on pilot workload. The Blue SWAT variable reported was the average of the SWAT scores reported after each run by the Blue pilots. SWAT data were also collected from the Red pilots.

The remaining variables were analyzed with the expectation that some insight into the use of the HMS/D would result. The LOS/HUD variable reflected the percentage of time the helmet sight indicated that the pilot's line-of-sight (LOS) fell outside the HUD, or, in other words, that the pilot was not looking at, or through, the HUD. The LOS/45 variable indicated the percentage of time the pilot's LOS was more than 45 degrees from aircraft boresight.

- The helmet mounted sight could be coupled to the radar and used to slew the radar field of regard, while the helmet display showed the positions of targets within the radar field of regard. This allowed the pilot to designate targets in Boresight and Supersearch radar modes at offset angles that would otherwise be too extreme. The Boresight variable was the number of designations of targets outside the normal field of regard in boresight mode. The Supersearch variable was the number of designations of targets outside the normal field of regard in Supersearch mode.

The First Time variable was the time between the beginning of a simulator run and the first weapon launch by a Blue aircraft. The First Range was the range between the Blue aircraft and its target at the time of the first launch. It should be noted that this datum could only be collected when the first weapon launched was an AIM-7.

5.2 ANALYSIS OF HMS/D QUANTITATIVE DATA

The quantitative data were analyzed in two parts. The data from the larger scenarios were submitted to a rigorous analysis of learning and HMS/D effects. This analysis also considered the pilot group (equivalent to the week of data collection) as a Factor. The data from the visual scenarios were analyzed for correlation among the variables analyzed. This analysis is more tolerant of the variation in types and order of scenarios, since data from each trial is being correlated only with other data from the same trial. The results from the larger scenarios will be reported first, followed by the results from the visual scenarios.

The statistical analysis employed for the larger scenarios was an analysis of variance treating the HMS/D -- HMS/D on and off - (HMD), the week in which the data were collected -- first or second (WEEK), and the block in which the data were collected -- block 1, 2, 3, 4 (BLOCK), as factors. Each week was divided into four blocks of eight trials, four of which were completed with the HMD on and four of which were completed with the HMD off. The first two blocks were always two-versus-four scenarios and the last two were always two-versus-eight scenarios. The interaction with the week of data collection will be discussed at a later point. Later blocks represent later trials where pilots had more opportunity to learn to use the HMS/D effectively. The type of scenario (whether

air base defense or sweep) and the force size were not factors in the analysis, since the effect of practice over blocks appeared more consistent.

The model employed was a split-plot factorial design (cf. Kirk, 1982). Weeks of data collection was the between - subjects (blocks in Kirk's description) treatment and HMS/D and block were within subjects variables. For this analysis, higher order interactions with the HMS/D factor were pooled with lower-order effects to form combined terms. Thus the interaction of HMS/D and block includes the main effect of block and the interaction of the week of data collection, HMS/D and block includes the main effect of week and both its two-way interactions. This model was small enough to be analyzed on the facility available and provided an economy of presentation in this report as well. This approach produces an analysis that has a greater chance of finding statistically significant effects. It is also more likely than usual that some of the effects reported would not prove reliable on further testing. This approach is justified in an attempt to discern a pattern in the diverse results of the study. This pattern is one key to understanding how the HMS/D was used in this study. It should be expected that all future simulation would show the same results.

The results of the analysis of the Blue Kills variable are shown in Figure 5-2. The HMS/D did not have an overall effect for the week, but did interact with the block variable to affect performance in different ways during the week. Figure 5-3 illustrates this result. Slightly fewer kills were achieved by the Blue aircraft with the HMD on during the early part of the week, but performance with the helmet improved dramatically in the final block. An average of 1.5 more kills per run were achieved by the blue aircraft with the HMD during the final block.

Dependent Variable: Blue Kills						
Source	DF	Type III SS	Mean Square	F Value	Pr<F	
HMD	1	0.02	0.02	0.01	0.920	
HMD x Block	6	31.59	5.27	3.40	0.007	
HMD x Block x Week	8	34.375	4.29	2.78	0.0131	
Error	48	74.25	1.54	—	—	

GP83-0078-2T

Figure 5-2. Analysis of Variance Summary Table for Blue Kills

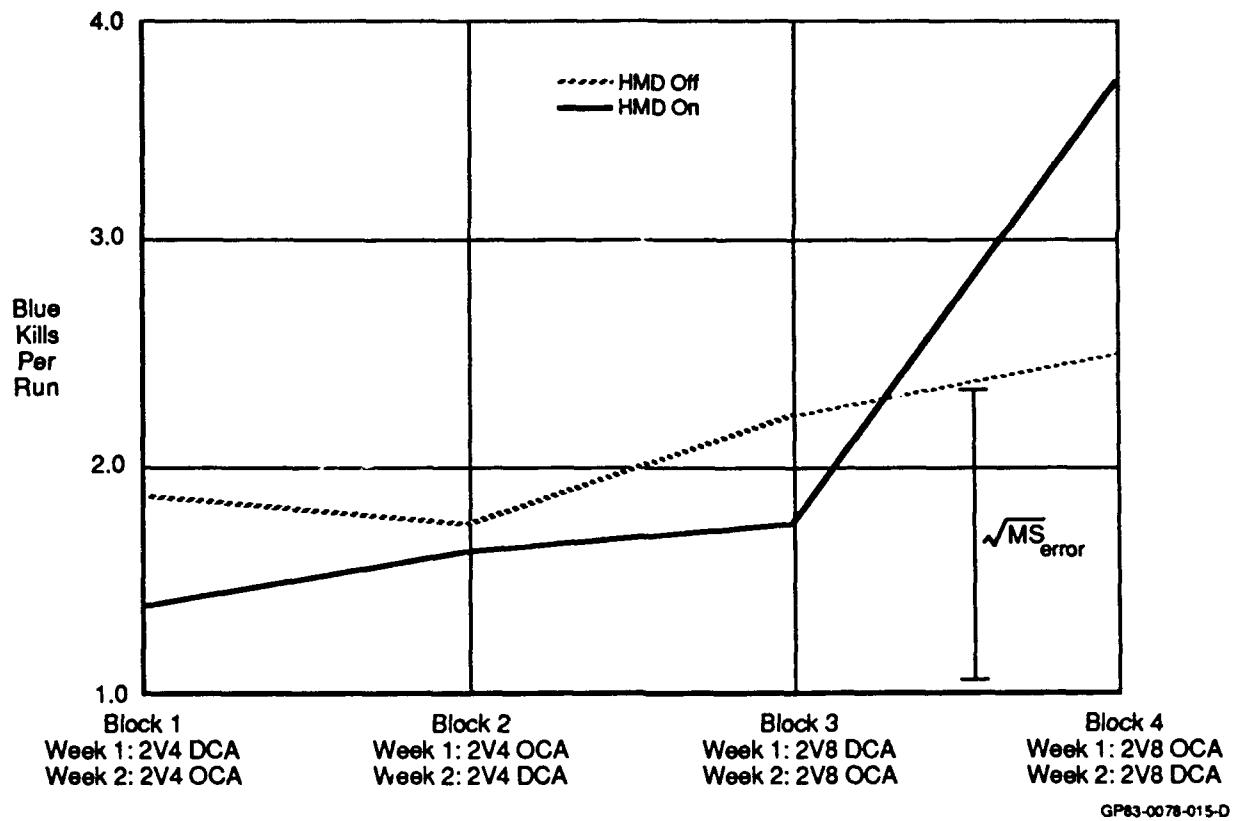


Figure 5-3. Average Kills Per Run for Blue Aircraft

The defensive performance of the Blue aircraft does not seem to have been affected by the variables examined. Figure 5-4 shows the results of the analysis indicating no statistically detectable effects on the Red Kills variable. Figure 5-5 bears out this conclusion, indicating that at no point was there as much as a 0.5 aircraft difference in the Red Kill variable as a function of the presence of the HMD.

Dependent Variable: Red Kills

Source	DF	Type III SS	Mean Square	F Value	Pr < F
HMD	1	0.14	0.14	0.19	0.6659
HMD x Block	6	1.59	0.27	0.36	0.8087
HMD x Block x Week	8	5.38	0.67	0.90	0.7484
Error	48	35.75	0.74	—	—

GP83-0078-4-T

Figure 5-4. Analysis of Variance Summary Table for Red Kills

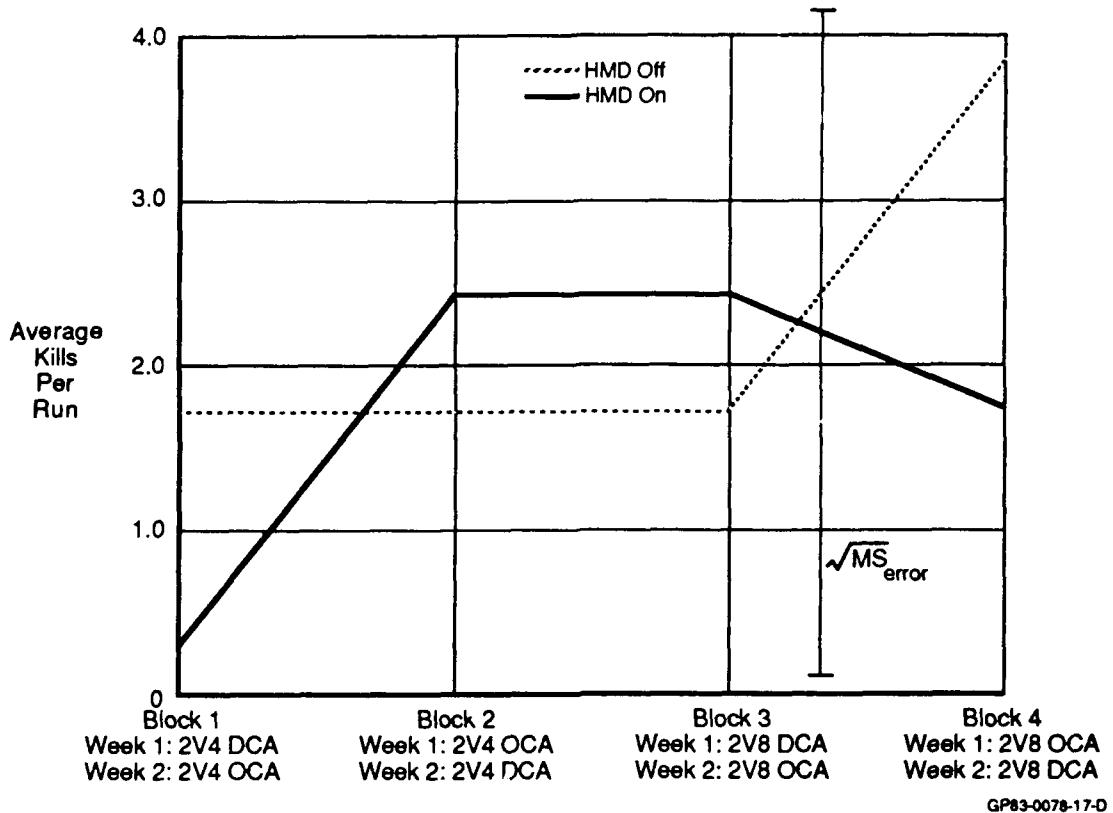


Figure 5-5. Average Kills Per Run for Red Aircraft

The workload of the F-15 pilots was reflected in the Blue SWAT variable. There was a significant interaction among the weeks, HMS/D and block variables due partly to consistently higher SWAT scores reported during the second week. The highest SWAT scores were associated with the HMS/D during the first three blocks of the second week as shown in Figure 5-6. The reversal of this trend in the fourth block is responsible for the crossover shown in Figure 5-7. The SWAT scores from the first week were more consistent with slightly lower scores reported while using the HMS/D throughout the week.

Dependent Variable: F-15 Pilot Workload

Source	DF	Type III SS	Mean Square	F Value	Pr < F
HMD	1	377.82	377.82	1.24	0.2710
HMD x Block	6	1548.55	258.09	0.85	0.54
HMD x Block x Week	8	15307.72	1913.46	6.28	0.0001
Error	48	14622.44	304.63	—	—

GP83-0078-3-T

Figure 5-6. Analysis of Variance Summary Table for F-15 Pilot Workload

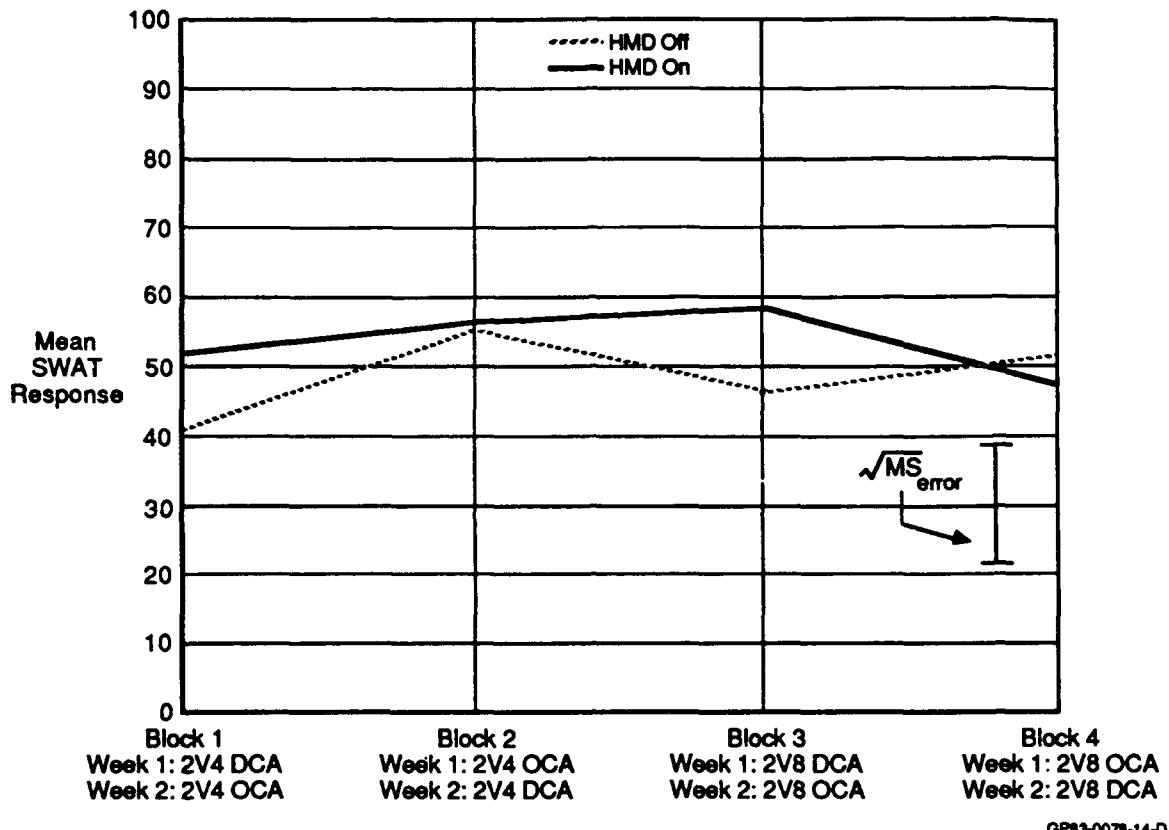


Figure 5-7. Average Blue Workload

GP83-0078-14-D

The workload of the Red pilots, reflected in the Red SWAT variable, showed a more definite pattern. The statistical analysis shown in Figure 5-8 indicates that Red pilot workload was not affected by whether or not the Blue pilots were using the HMD, but that the HMD factor and the block factor together did have a definite effect. Figure 5-9 shows the results graphically and suggests that Red pilot workload was higher when Blue pilots were using the HMD during the last block (and the first block), but was lower for the second and third block. It was felt that the first block was higher because the Red pilots had more difficulty learning to fly the MICS than the Blue pilots had learning to fly the F-15 cockpit. By the time of the last block the Blue pilots had been trained sufficiently to "make life more miserable" for the Red pilots.

Dependent Variable: Red Pilot Workload

Source	DF	Type III SS	Mean Square	F Value	Pr < F
HMD	1	5.64	5.64	0.03	0.8643
HMD x Block	6	6220.48	1036.75	5.42	0.0002
HMD x Block x Week	8	6155.88	749.48	4.03	0.001
Error	48	9174.50	191.14	—	—

GP83-0078-1-T

Figure 5-8. Analysis of Variance Summary Table for Red Pilot Workload

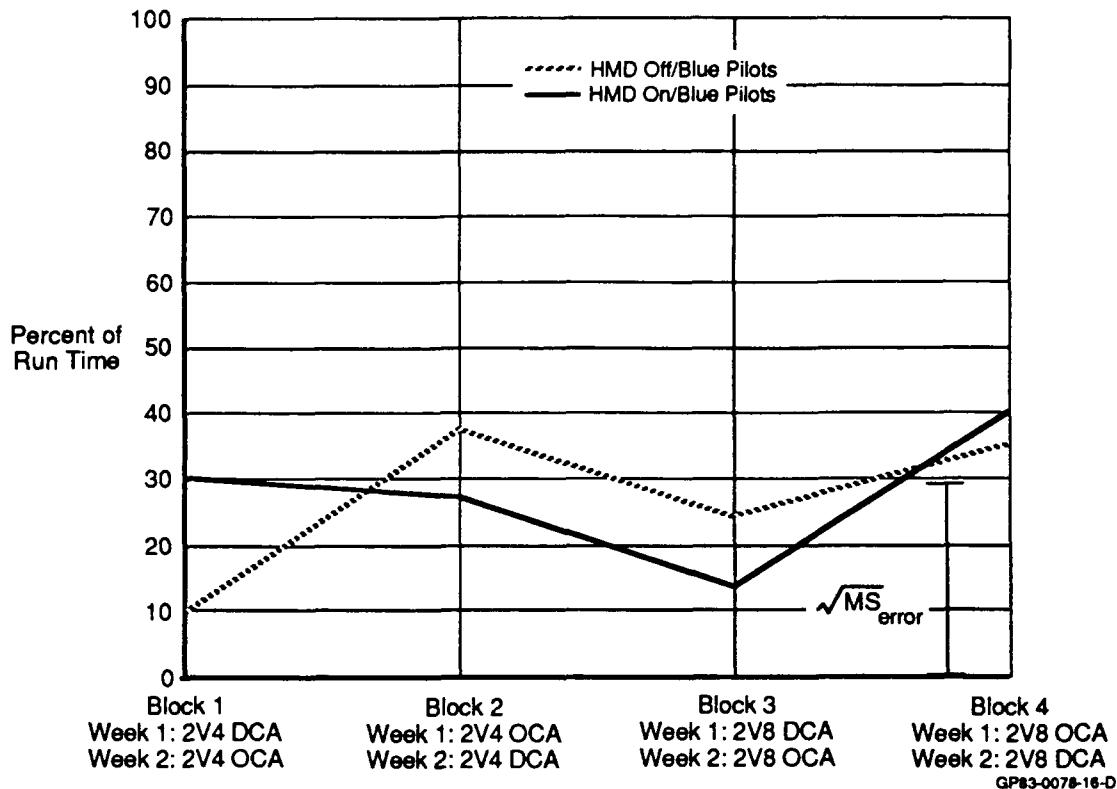


Figure 5-9. Average Red Pilot SWAT Score

The percentage of run time each pilot spent with his LOS outside the HUD field of view was not affected by the HMD or by the combination of the HMD and the block, according to the analysis summarized in Figure 5-10. As graphed in Figure 5-11, the LOSHUD data suggest a consistent difference between the HMD on and HMD off conditions during the first three blocks, converging in the fourth and final block. Although the analysis of variance reported in Figure 5-10 would support this conclusion, one entire cell was missing from the data and the correctness of the results cannot be assured.

**Dependent Variable: Percentage of Time Helmet Line of Sight
Was Outside the HUD**

Source	DF	Type III SS	Mean Square	F Value	Pr<F
HMD	1	86.81	86.81	0.59	0.44
HMD x Block	6	1251.36	208.56	1.43	0.22
HMD x Block x Week	7	14024.72	2003.53	13.72	0.0001
Error	43	6280.33	146.05	—	—

GP83-0078-11-T

**Figure 5-10. Analysis of Variance Summary Table for
Percentage of Time Outside the HUD**

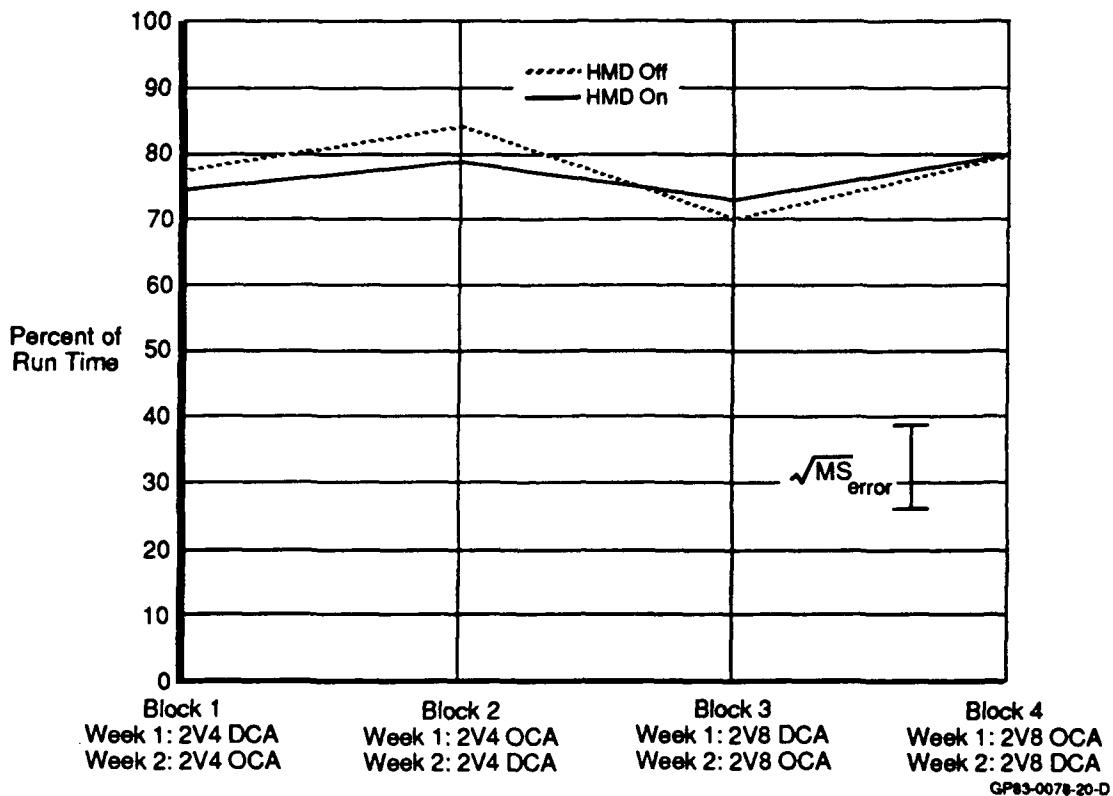


Figure 5-11. Percentage of Time Pilot LOS Was Outside the HUD

The results of the analysis of the LOS45 variable, shown in Figure 5-12, are similar to those for the LOSHUD variable. There were significant differences between the two pilot groups, including an effect of the HMD. The Blue pilots during the first week spent a substantially higher percentage of the time with their LOS more than 45 degrees off boresight during the two-versus-four scenarios than did the pilots of the second week. When graphed, as in Figure 5-13, the data suggest a tendency for higher off-boresight LOS angles during the early stages of the evaluation, declining at the end of the week. Again, the results must be interpreted cautiously due to the large number of missing values.

Dependent Variable: Helmet Line of Sight 45° or More Outside HUD

Source	DF	Type III SS	Mean Square	F Value	Pr < F
HMD	1	104.01	104.01	6.09	0.0182
HMD x Block	6	1253.31	208.88	12.23	0.0182
HMD x Block x Week	5	1066.01	213.20	12.38	0.0001
Error	38	648.92	17.08	—	—

GP83-0078-10-T

Figure 5-12. Analysis of Variance Summary Table for Helmet Line of Sight
More Than 45° Outside the HUD
(Thirteen Values Were Missing)

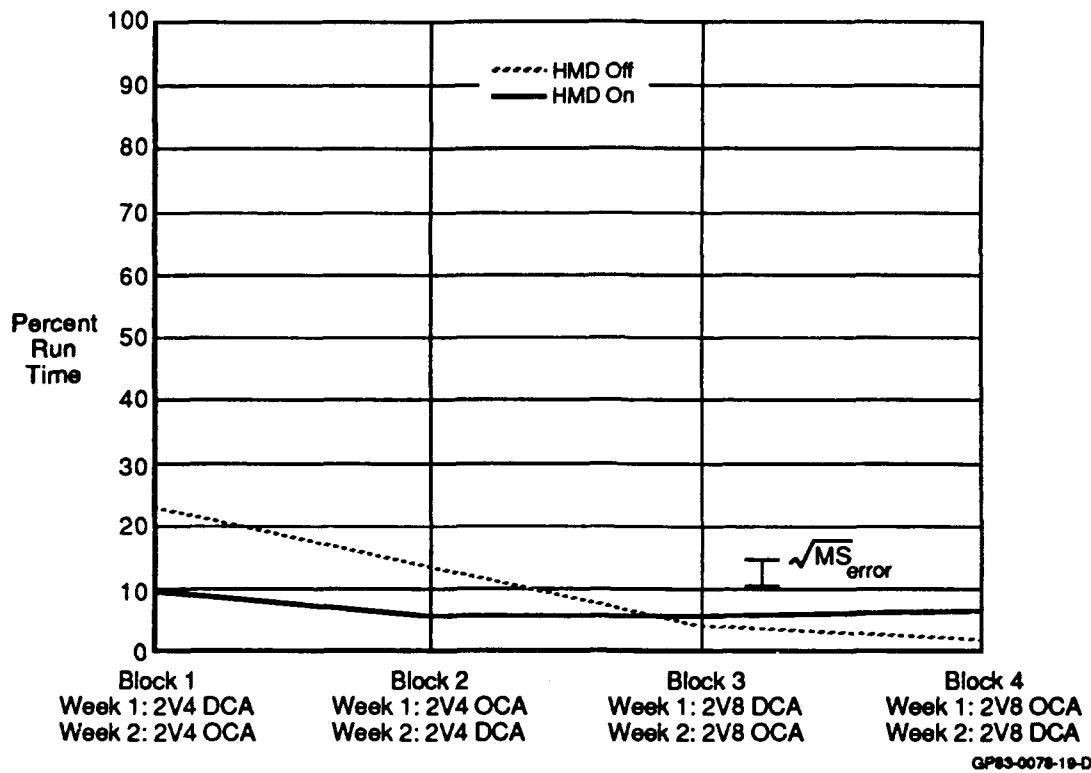


Figure 5-13. Percent of Time Pilot LOS Was More Than 45 Degrees Off Boresight

The HMD did have a significant effect on the Supersearch variable. Of the 35 targets designated in Supersearch radar mode outside the HUD, 29 were designated while the HMD was in use. This is reflected in the significant main effect for HMD in the analysis summarized in Figure 5-14. Most of these designations occurred during the first week of the evaluation, accounting for the interaction effect of week. Figure 5-15 illustrates these data, showing the general tendency for targets outside the HUD to be designated in supersearch only when the helmet was in use.

Dependent Variable: Designation of Targets Outside the HUD While in Supersearch Mode

Source	DF	Type III SS	Mean Square	F Value	Pr<F
HMD	1	6.89	6.89	8.22	0.0061
HMD x Block	4	6.96	1.16	1.39	0.24
HMD x Block x Week	4	21.88	2.73	3.26	0.0148
Error	48	40.25	0.84	—	—

GP73-0078-5-T

Figure 5-14. Analysis of Variance Summary Table for Supersearch Designations of Targets Outside the HUD

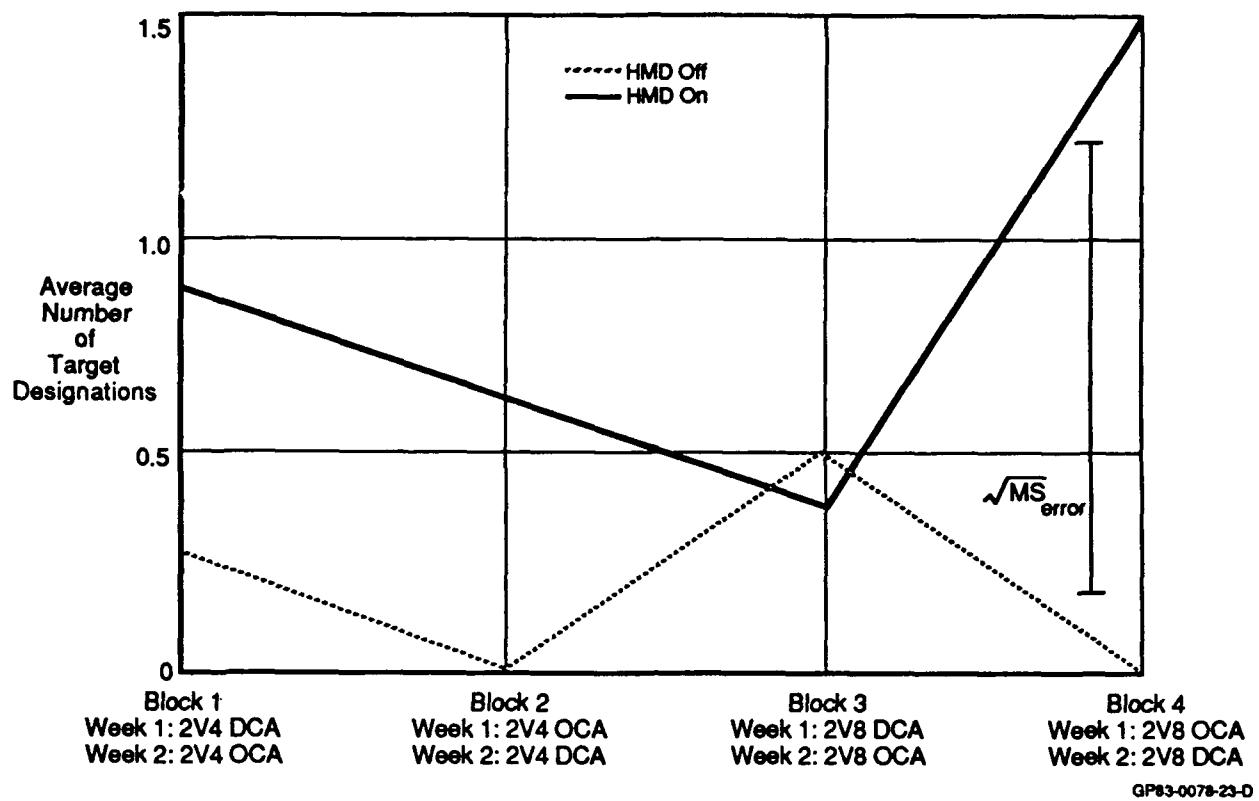


Figure 5-15. Number of Supersearch Designations Outside HUD

Only seven targets outside the HUD were designated in Boresight mode, four with the HMD and three without it. The disorderly results with this variable shown in Figures 5-16 and 5-17 are not surprising, given the small amount of data.

Dependent Variable: Designations of Targets
Outside the HUD in Boresight Mode

Source	DF	Type III SS	Mean Square	F Value	Pr < F
HMD	1	0.02	0.02	0.10	0.7491
HMD x Block	6	1.09	0.18	1.21	0.32
HMD x Block x Week	8	1.88	0.23	1.55	0.16
Error	48	7.25	0.15	—	—

GP83-0078-8-T

Figure 5-16. Analysis of Variance Summary Table for Designations
of Targets Outside the HUD While in Boresight Mode

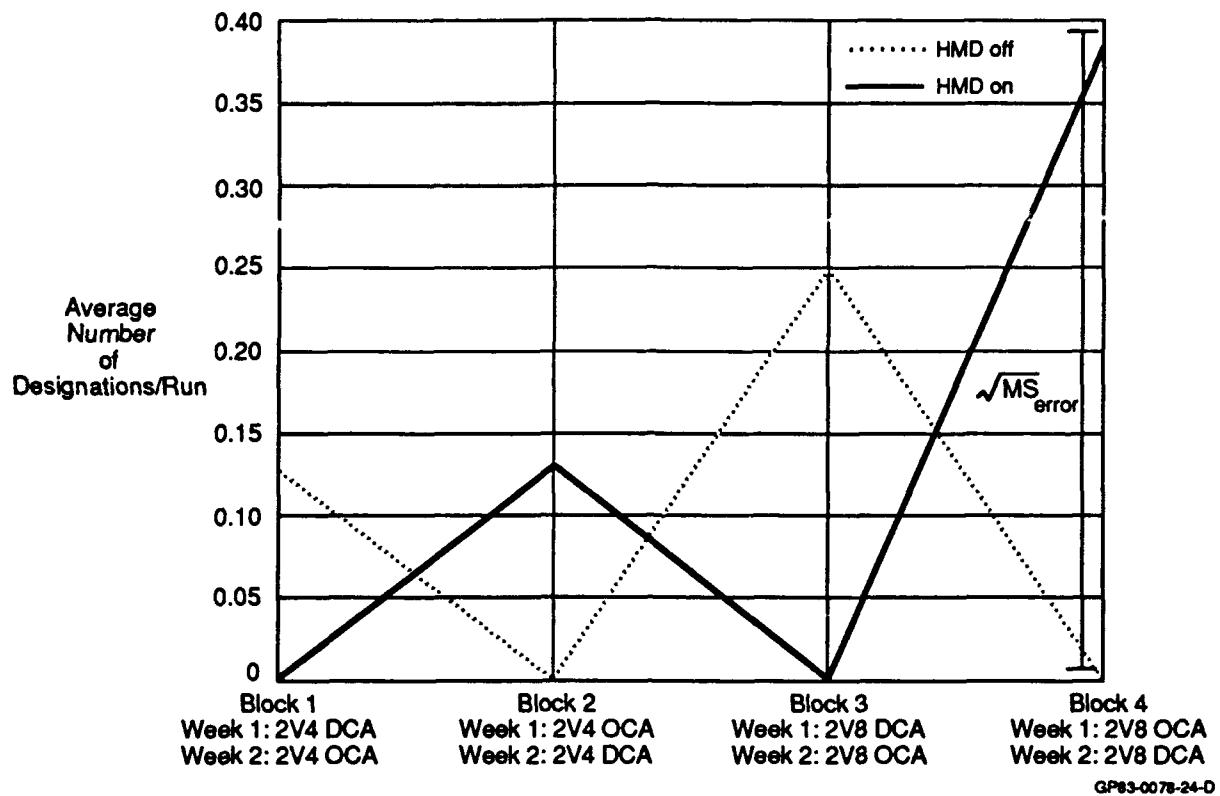


Figure 5-17. Number of Boresight Mode Designations Out of HUD

The number of AIM-9 launches did not show a relationship to the use of the HMD in the analysis reported to Figure 5-18. As Figure 5-19 shows, there were between one and two AIM-9 launches per run on the average throughout the week. There were an average of about 1.5 AIM-9 launches per run during the first week and about half that many during the second week.

Dependent Variable: AIM-9 Launches

Source	DF	Type III SS	Mean Square	F Value	Pr < F
HMD	1	1.27	1.27	0.47	0.4954
HMD x Block	6	14.09	2.35	0.88	0.52
HMD x Block x Week	8	43.38	5.42	2.02	0.06
Error	48	128.75	2.68	—	—

GP83-0078-7-T

Figure 5-18. Analysis of Variance Summary Table for AIM-9 Launches

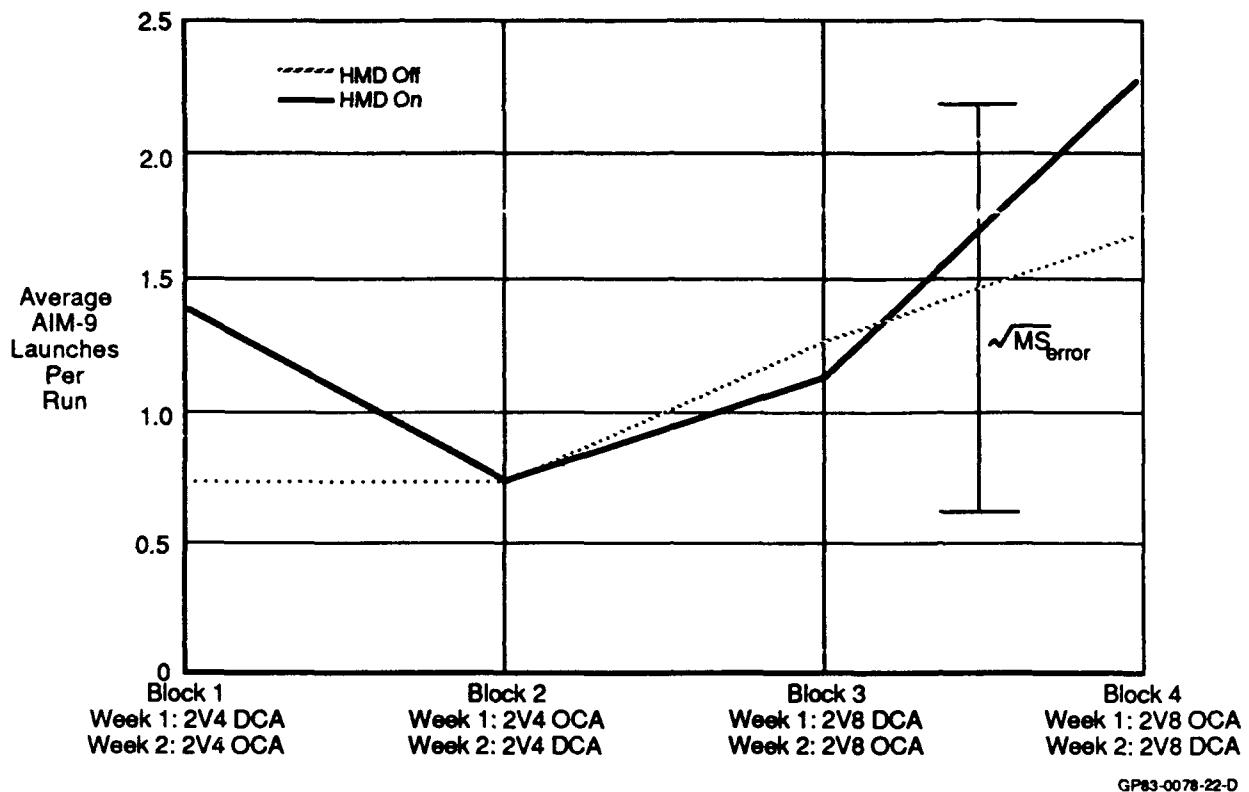


Figure 5-19. AIM-9 Launches

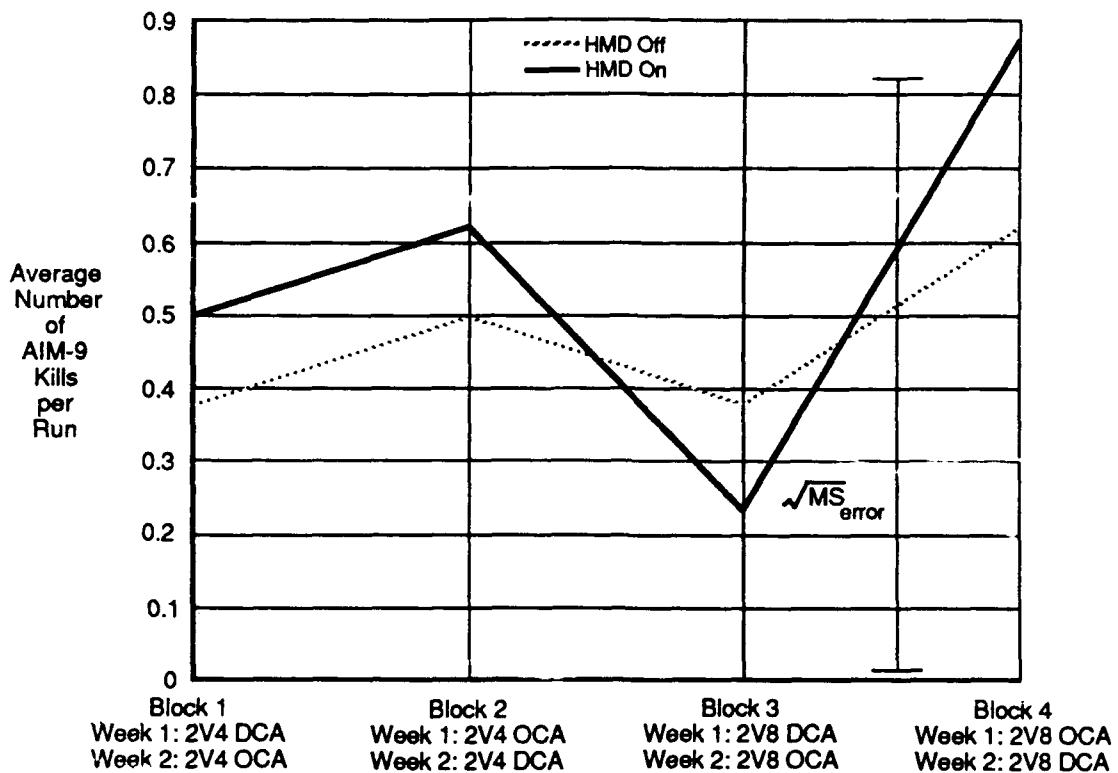
The analysis shown in Figure 5-20 indicates that the number of Blue kills achieved by the AIM-9 missile was not significantly affected by the use of the HMS/D, experimental block, or the pilot group, or any combination of these factors. Examination of the data in Figure 5-21 suggests more AIM-9 kills were achieved with the HMS/D than without it, except in the third block. Evidently, however, the reversal in the third block was sufficient to negate the trend favoring the helmet that was otherwise apparent.

Dependent Variable: AIM-9 Kills by Blue

Source	DF	Type III SS	Mean Square	F Value	Pr < F
HMD	1	0.14	0.14	0.27	0.6075
HMD x Block	6	1.97	0.33	0.62	0.71
HMD x Block x Week	8	6.63	0.83	1.57	0.16
Error	48	25.25	0.53	—	—

GP83-0078-6-T

Figure 5-20. Analysis of Variance Summary Table for AIM-9 Kills by Blue



GP83-0078-25-D

Figure 5-21. Average AIM-9 Kills Per Run

The time of the first launch was related to the use of the HMD/D. As Figure 5-22 shows, there was no constant effect of the HMD/D, but there was an effect of the HMD/D in combination with the block and the week of data collection. Figure 5-23 demonstrates a very consistent tendency for a longer elapsed time between start of the run and the first launch during the early runs, diminishing as the week proceeded until there was no difference during the final blocks. The difference between the time with and without the HMD/D diminishes from almost 20 seconds in the week to nearly zero at the end.

Dependent Variable: Time of First Launch

Source	DF	Type III SS	Mean Square	F Value	Pr < F
HMD	1	654.52	654.52	0.31	0.5787
HMD x Block	6	75316.37	12552.73	6.01	0.0002
HMD x Block x Week	6	52769.81	8794.97	4.21	0.0022
Error	40	83540.08	2088.50	—	—

GP83-0078-12-T

Figure 5-22. Analysis of Variance Summary Table for Time of First Launch

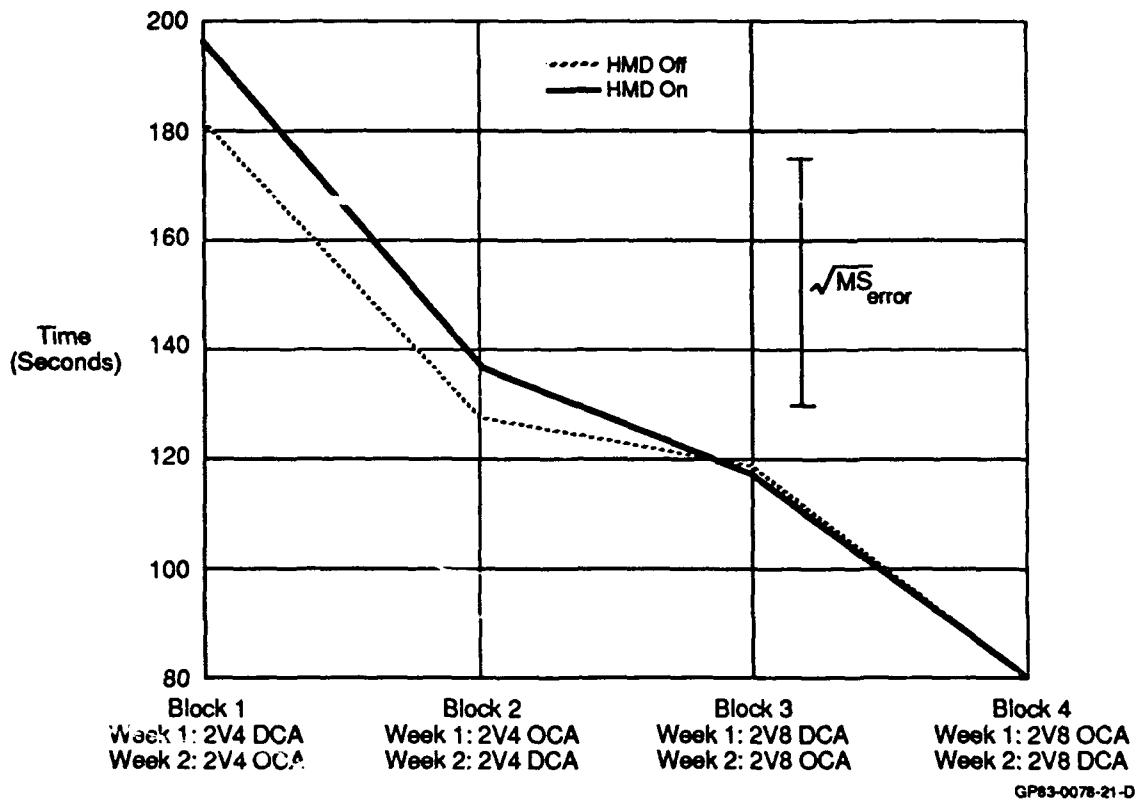


Figure 5-23. Average Time From Start of Run to First Launch

Range at first launch data was only available when the first launch was an AIM-7 launch, contributing to the large number of missing values for this variable: see Figure 5-24. Nevertheless, during the two-versus-four missions in blocks 1 and 2 in Figure 5-25, the first launch consistently came at a greater range when the HMS/D was in use. This trend was reversed in block three, the first block of two-versus-eight missions, but then seemed to reassert itself in block four, but no statistically significant trend emerged. Two cells were missing entirely from the data, so the statistical results must be interpreted cautiously.

Dependent Variable: Range at First Launch

Source	DF	Type III SS	Mean Square	F Value	Pr<F
HMD	1	15472263.82	15472263.82	0.34	0.56
HMD x Block	6	486122233.41	81020372.23	1.76	0.13
HMD x Block x Week	6	314676668.87	52446111.48	1.14	0.36
Error	38	1749832050	46048211.9	—	—

GP83-0078-9-T

Figure 5-24. Analysis of Variance Summary Table for Range of First Launch
(Thirteen Values Were Missing)

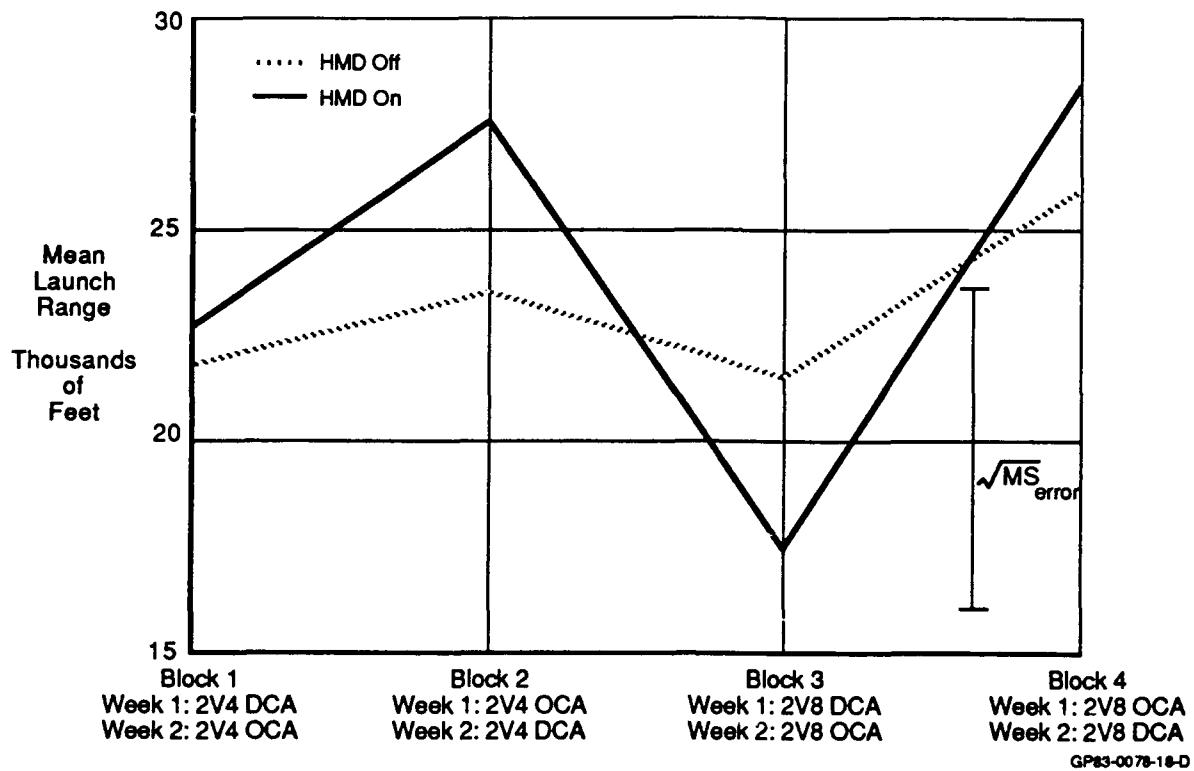


Figure 5-25. Range at First Launch

The differences between the weeks of data collection in mission success are summarized in Figure 5-26. Exchange ratios were very favorable to Blue aircraft during the first two blocks of week one. Difficulties experienced by Red pilots flying the MICS stations were probably a major factor here. Changes in training and in the flight models used were incorporated for the second week. The results for the first two blocks of the second weeks show lower exchange ratios. In both weeks (except the first two blocks of week one) there is a slight disadvantage for the helmet until the final block. Also, in both weeks, there was a significant advantage for Blue aircraft when the HMS/D was in use. When the data of both weeks are averaged together the exchange ratio for the final block was 3.75 with the HMS/D versus 1.8 without. This result will be discussed further in Section 6; the important point here is that the same trends were present in both weeks.

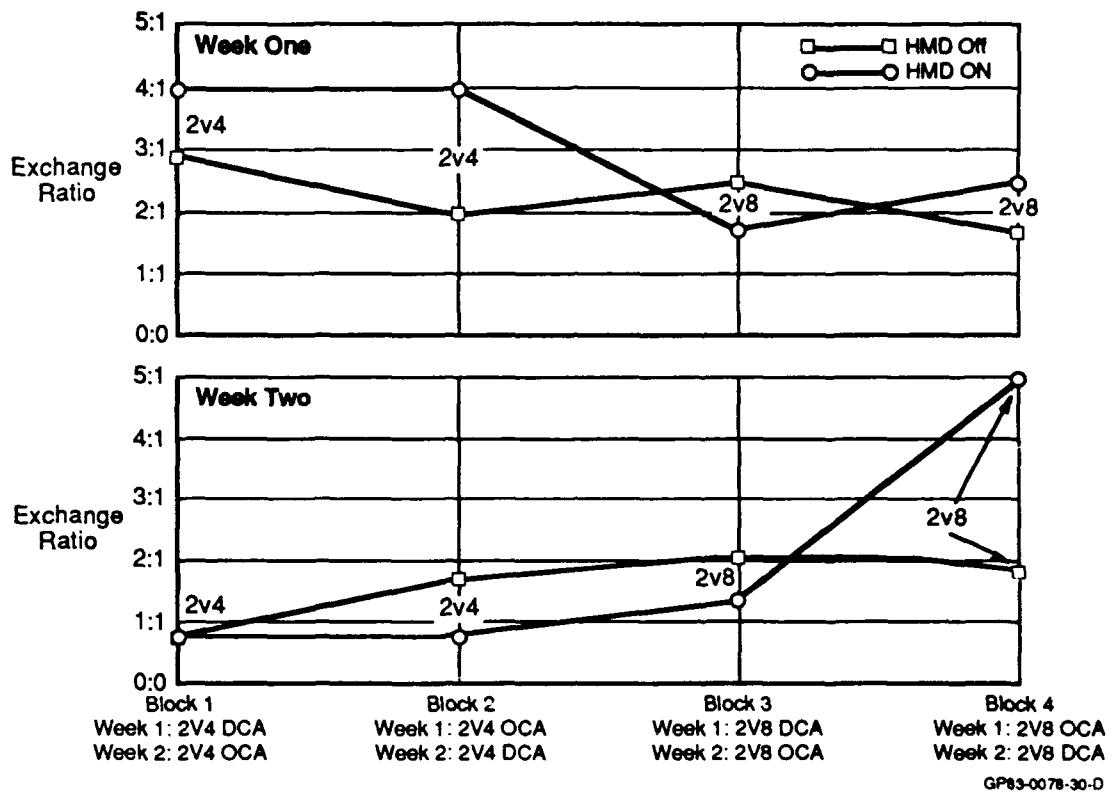


Figure 5-26. Exchange Ratios for Each Week

The results of the visual engagement did not lend themselves to any clear interpretation. In the 1v1v1v1 scenario, slightly better results were achieved with the HMS/D than without it: 0.85 average Blue kills per mission with the HMS/D versus 0.75 without it and 0.69 Red kills when the F-15 pilots used the HMS/D versus 0.75 when HMS/D was not in use. The corresponding exchange ratios are 1.23 with the HMS/D and 1.00 without it. The results in the 2v2 scenario were less distinct. An average of 1.30 Blue kills per mission were obtained both with and without the HMS/D. Red kills averaged 0.90 per mission when the HMS/D was in use compared to 0.80 when it was not.

The results from the visual scenarios were also cross-correlated to form two correlation matrices, one for trials without the HMS/D (Figure 5-27) and one for trials with it (Figure 5-28). The entry in each cell in this matrix represents the tendency for two variables to vary together. A value near positive one indicates a strong direct relationship, a number near negative one indicates a strong inverse relationship.

	Blue Kills	Blue Losses	Boresight Outside HUD	Supersearch Outside HUD	Blue Swat	Red Swat	AIM-9 Launches	AIM-9 Kills	Time of First Launch	LOS Outside HUD	LOS 45° Outside HUD
Blue Kills	1 00000	-0 18888	0 27060	-0 03217	-0 39542	-0 35980	0 62944*	0 69584*	-0 04548	-0 41517	-0 35927*
Blue Losses			0 03674	-0 06989	0 16189	-0 48374*	-0 26169	-0 43183	-0 08584	-0 04509	0 16279
Boresight Outside HUD				-0 15019	-0 32410	-0 49009*	0 29841	0 46402*	-0 05816	-0 29531	-0 01286
Supersearch Outside HUD					0 31453	0 33034	0 12373	0 14712	-0 17603	0 15681	0 36631
Blue Swat						0 55184*	-0 14326	-0 18746	-0 07361	0 55438*	0 39265
Red Swat							-0 13120	0 02184	0 17442	0 71936*	0 46587*
AIM-9 Launches								0 78700*	0 04914	-0 15630	-218 65
AIM-9 Kills									-0 05448	-0 10035	-0 6604
Time of First Launch										0 27925	-0 14730
LOS Outside HUD											0 58680*
LOS 45° Outside HUD											

*Indicates a correlation that would be expected in fewer than 5 of 100 cases

GP83-0078-28-T

Figure 5-27. Correlation Matrix for Visual Engagements With HMD On

	Blue Kills	Blue Losses	Blue Swat	Red Swat	AIM-9 Launches	AIM-9 Kills	Time of First Launch	LOS Outside HUD	LOS 45° Outside HUD
Blue Kills	1 00000	-0 07176	-0 48773*	-0 19159	0 56380*	0 57387*	0 30797	-0 10530	-0 35927
Blue Losses			0 23528	0 19367	-0 30500	-0 47875*	0 20309	0 26043	0 29395
Blue Swat				0 05754	-0 40484	-0 65612*	-0 35349	0 49983*	0 22226
Red Swat					-0 37842	-0 21844	0 19687	0 38215	0 15705
AIM-9 Launches						0 61884*	0 06906	-0 15388	-0 09231
AIM-9 Kills							0 24071	-0 19661	-0 24306
Time of First Launch								0 05082	-0 04866
LOS Outside HUD									0 48924*
LOS 45° Outside HUD									

*Indicates a correlation that would be expected in fewer than 5 of 100 cases

GP83-0078-29-T

Figure 5-28. Correlation Matrix for Visual Engagements With HMD Off

Some high correlations emerged in both matrices. Blue kills were correlated with AIM-9 launches and AIM-9 kills both with and without the helmet. AIM-9 kills were also correlated with AIM-9 launches and the two LOS measures were correlated in both cases. Without the helmet, Blue kills were also correlated with blue SWAT scores, which was correlated in turn with AIM-9 kills. These variables were not correlated when the helmet was not in use. Five variables correlated with Red SWAT scores when the HMS/D was in use. These included the Red kills variable. The number of designations outside the HUD in boresight mode, Blue SWAT scores, and both LOS variables. The correlations with Red kills and boresight mode designation were negative. There was also a negative correlation between Red kills and the LOS45 variable, and positive correlations between boresight designations and AIM-9 kills and Blue SWAT and LOS HUD.

5.3 QUALITATIVE DATA SUMMARY

Each day during the tests pilot comments were collected during debriefing sessions, and the pilots completed questionnaires at the end of the tests. They pointed out several distinct tactical advantages of the HMS/D and made some recommendations for improving the present system. Half of the pilots were so impressed with the tactical advantages that they recommended classifying the program.

5.3.1 Tactical Advantages - The following summarizes pilot comments and responses about the advantages of the HMS/D.

1. Easier to perform radar acquisition within visual range (WVR).

This is one of the features the pilots liked best. Presently, when an F-15 pilot sights another aircraft, he must rapidly decide which of four automatic acquisition modes he will use: Vertical Scan, Supersearch, Boresight, or Auto Guns. Tradeoffs between these modes include ease of use and speed of acquisition. The pilot must quickly assess these and choose the best mode for the present situation.

The HMS/D helped this problem considerably by reducing the choices to only two modes: a wide search mode (helmet "supersearch") and a narrow, focused mode (helmet "boresight"). Both modes were slaved to the helmet, making both very easy to use. The only decision was whether the situation dictated the higher accuracy available in the helmet boresight mode. Normally, this accuracy would be required only if the pilot had to select his target from two or more that are very close together (e.g., supporting an engaged wingman who is in a tight turning fight).

2. The HMS/D provided considerable assistance in obtaining and maintaining visual sighting of a previously acquired target.

One of the Aggressor pilots stated, "Anything that points your head and puts your eyes on the target will give you a significant advantage." All pilots agreed that the HMS/D with the pointer arrow and TD box accomplished this. Pilots have used TD boxes for some time, but they have always been restricted to the HUD field of view which means that he has to point the aircraft at the target. That is not always tactically sound.

Pilots found the ever present TD box on the HMS/D enabled them to take their eyes off a visual target to clear their 6:00 o'clock or to check the position of another aircraft maneuvering near them. They could do this because they had steering to place their eyes quickly back onto the original target. Without the HMS/D they tended to remain "padlocked" on the target, often missing other nearby aircraft.

The TD box also enabled them to determine if the canopy bow, magnetic compass, or other aircraft obstruction was currently blocking their view of the target. Once this could be observed, a pilot could easily compensate, by moving his head or the aircraft. However, after observing this, all the pilots wondered how many times in the past a similar obstruction had caused them to miss the initial visual sighting of a target acquired through radar.

3. The HMS/D saved time in visual attacks.

The "first sight" advantage is often the most significant one. In an age of all-aspect IR missiles, first sight often translates into the kill, because upon sighting, the pilot points the aircraft at the target, directs the seeker into self-track, and shoots as soon as seeker track is confirmed. However, pointing the aircraft can impose a 10 to 15 second time delay. This could be all the time needed for a fighter equipped with the HMD to get the first shot.

The HMD turned into a time saver in one other fashion. Because the Sidewinder seeker line of sight was available, the pilot did not need to point the HUD at the target to confirm that the missile was in fact tracking the desired aircraft. Thus, the pilots could launch off boresight with greater confidence. The pilots themselves cautioned that this tempted them to take bad shots at times (e.g., out of range when the radar lock on step was omitted), but they felt they could train to eliminate this tendency.

4. It is very helpful to have weapons data available when visually "padlocked".

The pilots liked the capability of observing the shoot cue and target identification (e.g., IFF) without having to look at the HUD. The pilots felt that this capability enabled them to exercise visual search more freely since they did not have to watch the HUD and/or radar to determine when launch criteria had been satisfied or when the identification had been obtained. In some cases, the pilot was already lining up his next shot while waiting for a radar target to reach in range, firing his first missile on the HMD shoot cue. This was especially helpful when the next target had been acquired visually.

The pilots said they would like to see AIM-7 time-to-go on the HMS/D.

5. The ability to launch visual AIM-9 missiles while performing AIM-7 missile illumination is a big improvement.

During the AIM-7 time of flight, the pilot must restrict his maneuvering to keep from losing the target out of the radar field of regard. When another target is visually acquired, the pilot must maneuver carefully in any attempt to launch an AIM-9, since maneuvering may result in loss of the previously launched AIM-7. The HMS/D made this situation easier to handle, since the pilot could point the AIM-9 with the helmet, and continue to fly his present flight path for AIM-7 guidance.

6. With the HMS/D there is no need to sacrifice BFM (basic fighter maneuvers) to launch AIM-9 L/M missiles.

The HMS/D resolved the dilemma of giving up positional advantage to go for a quick kill or maintain positional advantage, but prolong the fight. The HMS/D permitted the pilots to use the full maneuverability of the missiles to supplement the aircraft's maneuverability and achieve the best of both options in his tactics.

7. With the HMS/D there is no need to sacrifice BFM to perform full system gun attacks.

The pilot often has to perform considerable BFM maneuvering to obtain a gun attack. Though seldom the weapon of choice, the pilot may be forced into using the gun in a very tight turning fight. The gun can be fired completely visually, estimating the necessary lead angles. However, the more ideal attack is performed using the radar to obtain a track on the target. This enables the aircraft computer to determine lead for the pilot and position the gunsight accordingly. The pilot can use auto-acquisition methods to get the radar track, but sometimes, the necessary BFM makes this difficult to accomplish. As with the AIM-9 attack, the HMD makes it possible to obtain radar track without sacrificing the BFM. This means that the radar has a chance to settle down, and it will provide good information as the pilot prepares to take the gun shot.

The following summarizes the pilots' suggestions for improvement of the HMS/D.

1. Remove the horizon line and heading scale.

None of the pilots found these particularly useful. They intended to ignore these items at first, and when they discovered that we could remove them for the test, all requested that they be removed. Half of them felt the same way about the airspeed and altitude numbers.

2. Concentrate on the WVR environment.

The pilots did not feel that the HMD provided a significant advantage in the BVR environment. They preferred using the available cockpit displays for BVR work, and felt that the HMD did not add to present capabilities. However, all felt it was a major improvement for WVR operations, and all stated that they needed these capabilities now.

3. The field of view should be slightly larger.

All pilots commented that the present HMS/D (120° FOV) forced them to chase the TD box on occasion in an attempt to keep it within the HMD FOV. They sometimes found this activity counter-productive. When asked what they thought would be a more useful size, they agreed that something approaching the size of the HUD FOV would be desirable. The present HUD FOV is approximately 20°.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The data are consistent with the theory that a combination of 1) pilots learning to use the HMS/D, and 2) adapting the HMS/D pilot vehicle interface to the individual pilot (in the form of customized declutter modes, and letting the pilots choose their preferred helmet and cockpit) provided a significant tactical advantage when using the HMS/D during the last block of test data. Introducing new equipment or a performance feature in a system typically causes performance to initially decrease while the operator relearns how to use it. Then performance will increase as he begins to capitalize on the added capability.

The advantage gained with the HMD/S may have been accentuated by the two-versus-eight scenarios in blocks three and four. In these larger scenarios, it was more difficult for the pilots to track all Red aircraft in BVR, and unexpected encounters at short range seemed to be more frequent. It was anticipated that the HMS/D would provide an advantage in these WVR circumstances.

Figure 6-1 shows the changes in exchange ratio as a function of the test block and whether the HMS/D was on or off. Figure 6-2 shows the changes in Red and Blue workload for the same conditions. Data for the first block is questionable because the pilots were still learning the simulation. The adjustment was particularly difficult for the Red Pilots flying the MICS stations. When the first block data are excluded, the exchange ratio data of Figure 6-1 shows that there is an advantage for the HMD off condition during the middle (Blocks 2 and 3) of the testing period. Similarly, Figure 6-2 shows that during blocks 2 and 3, Blue pilot workload is lower and Red pilot workload higher when the Blue pilots had the HMS/D off. Both trends are dramatically reversed in the fourth block however.

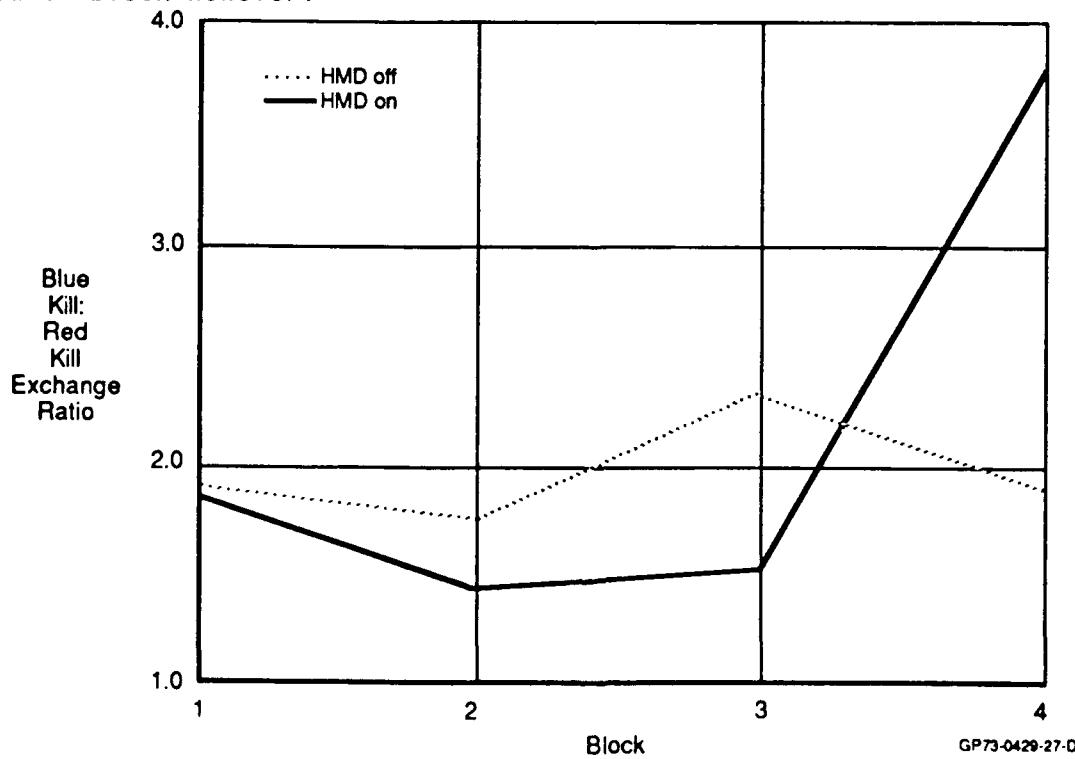


Figure 6-1. Exchange Ratio Results

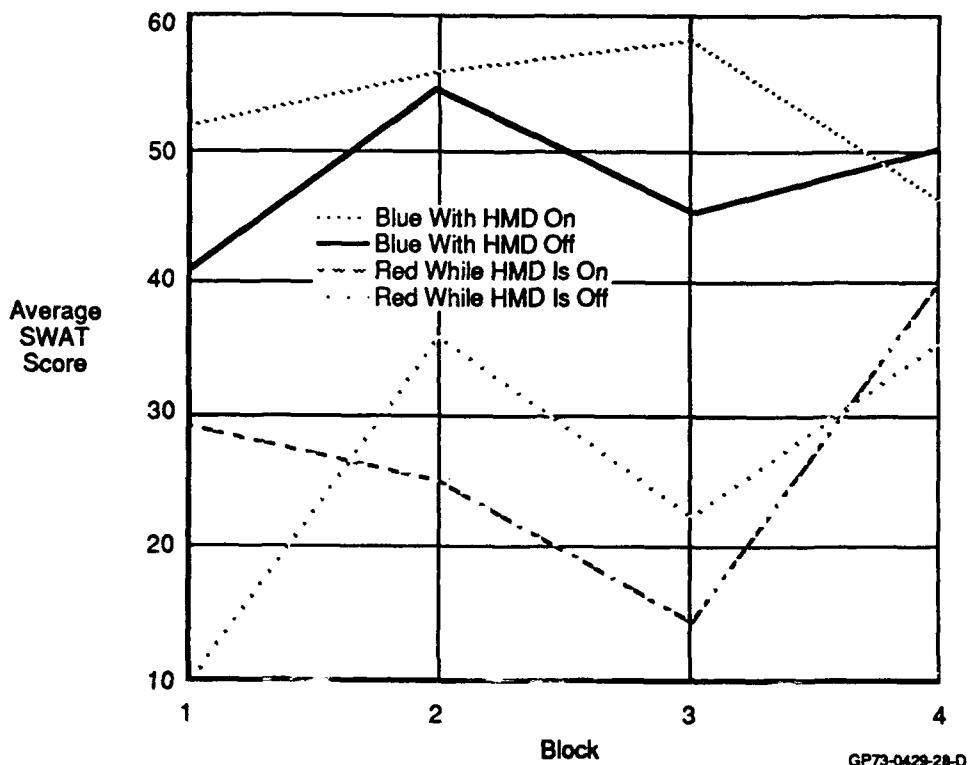


Figure 6-2. Red and Blue SWAT Scores

There is a marked exchange ratio advantage for the Blue pilots with the HMS/D during the fourth block. This advantage is traceable to a 50 percent increase in the number of kills achieved (an average of 3.75 kills with the HMS/D versus an average 2.5 kills without it during the fourth block). The workload data corroborate this trend, indicating lower workload for Blue pilots and higher workload for Red pilots while the HMS/D was in use.

The time of first launch results also indicate that use of the helmet changed during the course of the evaluation. At the beginning of the evaluation the average time of first launch was later with the HMS/D than without it. By the end of the evaluation, there was no difference between the HMS/D conditions. This is consistent with the idea that the HMS/D did not become well integrated into the pilots' repertoire of skills until the latter part of the evaluation. Both the LOSHUD and LOS45 data showed a tendency for the results from the two helmet conditions to converge over the course of the week.

To summarize the data analyses reported in Section 5, only the Supersearch and LOS45 variables were significantly affected by the HMS/D in isolation. In both these cases higher order interactions were also present when combined with the block factor or the block and week factor together, though, the HMS/D significantly affected the number of Blue Kills, Red and Blue pilot SWAT scores, AIM-9 launches the time of first launch, and the measurement of helmet.

The qualitative, or subjective, data is more useful than the quantitative data because it uses the experience of the pilots to project the value of the HMS/D into a real operational scenario that is untethered by the simulation limitations.

The pilots said that the HMS/D made it easier to do WVR radar acquisitions, and get visual sightings of acquired target, saved time in WVR attacks, provided helpful weapon data while visually tracking a target, and added tactics capability by easing simultaneous AIM-9 and AIM-7 attacks, and avoided sacrificing BFM (basic fighter maneuvers) to launch an AIM-9 or perform a full system gun attack.

They were particularly impressed with the time saved in a WVR attack and the ability to make AIM-9 launches while maneuvering.

In several of the test engagements, the Aggressor pilot obtained the first sighting, while the aggressor maneuvered to shoot, the F-15 pilot spotted him. Because the F-15 pilot was HMS/D equipped he did not have to maneuver his aircraft and was able to launch the first missile. This generally had one of two results:

- o The Aggressor was killed before he was able to complete the pointing maneuver. Therefore, he never got the shot off.
- o The Aggressor had to break off his attack and defend himself from a missile launched by the Eagle pilot. While the Aggressor was occupied in this fashion, the Eagle pilot maneuvered to a position of advantage.

In either case, the F-15 pilot was able to rapidly turn a bad situation into one where he had the upper hand because he could direct his IR missile seekers without having to perform an aircraft maneuver. The pilots referred to this capability as a "looks could kill" system, and one pilot stated that the combination of the HMD and the AIM-9 L/M should be called "hamburger helper". They felt that this capability was the greatest advantage of the HMD.

One of the pilots said, "The time saved using the helmet could be one pilot's lifetime."

Currently, the only way to launch an AIM-9L/M missile visually is to point the aircraft so that the target is within the seeker field of view. Unfortunately, pointing directly at the target aircraft may not be a sound tactical move. If the target is in a high G break turn, the pilot may need to maneuver out of the plane of the turn in order to maintain his positional advantage (i.e., remain behind the target). In pointing at the target, the target's turn may succeed in forcing the attacker into a neutral situation where neither has a clear cut advantage. The fighter pilot is faced with the choice of whether to go for the quick kill or to maintain his positional advantage. If he opts for the quick kill, the missile may fail to guide or fuse, and the pilot may lose his advantage with nothing gained. If he maintains his positional advantage, the fight is prolonged, and other enemy aircraft are given a chance to reach the fight and support the target.

With the HMS/D, the F-15 pilot can have it both ways. He flies the aircraft as necessary to maintain the advantage, because it is not required that he point at the target for seeker acquisition. While performing good BFM, he uses the helmet to drive the seeker onto the target. Then, when he achieves missile parameters, he launches the missile. This enables him to accomplish a visual missile attack without sacrificing positional advantage.

Overall, all pilots (including the Aggressor pilots) who performed the HMS/D evaluation thought that this was a vital system and one that is needed in present fighter aircraft. As one fighter pilot stated, "The advantage of having the HMD over having just a HUD is like the difference between CCIP (constant computing impact point) and an iron bomb sight." In other words, pilots feel the HMS/D provides as much improvement to air-to-air operations as weapons computers have provided in air-to-ground operations.

These results indicate the development of the HMS/D system should continue. There were areas of improvement that should be taken care of before the system would become operational. These should be addressed with simulations, engineering flight tests, and additional vendor work to improve the design and system integration concepts.

LIST OF ABBREVIATIONS

A/A	Air to Air
A/C	Aircraft
A/D	Air Data
A/G	Air to Ground
AAI	Air-to-Air Interrogate
ACM	Air Combat Maneuvering
ACS	Armament Control System
ADI	Attitude Director Indicator
AGL	Above Ground Level
AHRS	Attitude-Heading Reference Set
ASL	Azimuth Steering Line
ATO	Air Tasking Order
AUTO	Automatic
AVMUX	Avionics Multiplex Bus
BARO	Barometric
BDA	Bomb Damage Assessment
C2	Command and Control
CAS	Calibrated Airspeed
CC	Central Computer
CCC	Central Computer Complex
CLNC	Clearance (for TF operations)
CLR	Clear
CNI	Communication Navigation Identification
CRT	Cathode Ray Tube
CRS	Course
DBS	Doppler Beam Sharpening
DCLTR	Declutter
DDU	Display Driver Unit
DEST	Destination
DPT	Display Processor/Tracker
DRD	Data Readout Displays
DTM	Data Transfer Module
DWN	Down
EADI	Electronic ADI
EHSI	Electronic Horizontal Situation Indicator
EMERG	Emergency
EMIS LMT	Emission Limit
ENTR	Enter
EO	Electro-Optical

LIST OF ABBREVIATIONS (Continued)

FEBA	Forward Edge of Battle Area
FLIR	Forward Looking Infrared
FOV	Field of View
FWD	Forward
G	Gravity
GC	Gyrocompass
HBST	Helmet Boresight
HDD	Head Down Display
HDG	Heading
HMD	Helmet Mounted Display
HOTAS	Hands on Throttle and Stick
HSD	Horizontal Situation Display
HSEL	Heading Select
HSS	Helmet Supersearch
HUD	Head-Up Display
I/P	Identification of Position
IDENT	Identification
IFF	Identification, Friend or Foe
IIR	Imaging Infrared
IMC	Instrument Meteorological Conditions
IN RNG	In Range
INS	Inertial Navigation System
IP	Instructor Pilot
IR	Infrared
JTIDS	Joint Tactical Information Distribution System
K	Knots
KCAS	Knots, Calibrated Air Speed
KT	Knot
LOS	Line of Sight
M	Mach
M/V	Magnetic Variation
MACS	Manned Air Combat Simulator
MAN	Manual
MAV	Maverick
MC	Mission Computer (see CC)
MCAIR	McDonnell Aircraft Company
MDEC	McDonnell Douglas Electronic Company
MICS	Manned Interactive Control Station
MK	Mark

LIST OF ABBREVIATIONS (Continued)

ML	Mental Effort Load
MPCD	Multipurpose Color Display
MPD	Multipurpose Display
MR	Milliradian
MRM	Medium Range Missile
MSIP	Multi Staged Improvement Program
NAV	Navigation
NAVDSG	Navigation Designation
NCI	Navigation Control Indicator
NM	Nautical Mile
NMPP	Nautical Miles per Pound
NORM	Normal
O/S	Offset
OFP	Operational Flight Program
PACS	Programmable Armament Control Set
POSN	Position
PP	Present Position
PPI	Plan Position Indicator
PRF	Pulse Repetition Frequency
PRI	Priority
RAM	Raid Assessment Mode
RDR	Radar
RDY	Ready
RF	Radio Frequency
RNG	Range
ROE	Rules of Engagement
RTCL	Reticle
RWR	Radar Warning Receiver
SAC	Strategic Air Command
SAR	Synthetic Aperture Radar
SCL	Scale
SL	Psychological Stress Load
SRM	Short Range Missile
STAN EVAL	Standard Evaluation
STBY	Standby
STOR	Store
STT	Single Target Track
SWAT	Subjective Workload Assessment Technique
TAC	Tactical Air Command
TACAN	Tactical Air Navigation
TBD	To Be Determined

LIST OF ABBREVIATIONS (Concluded)

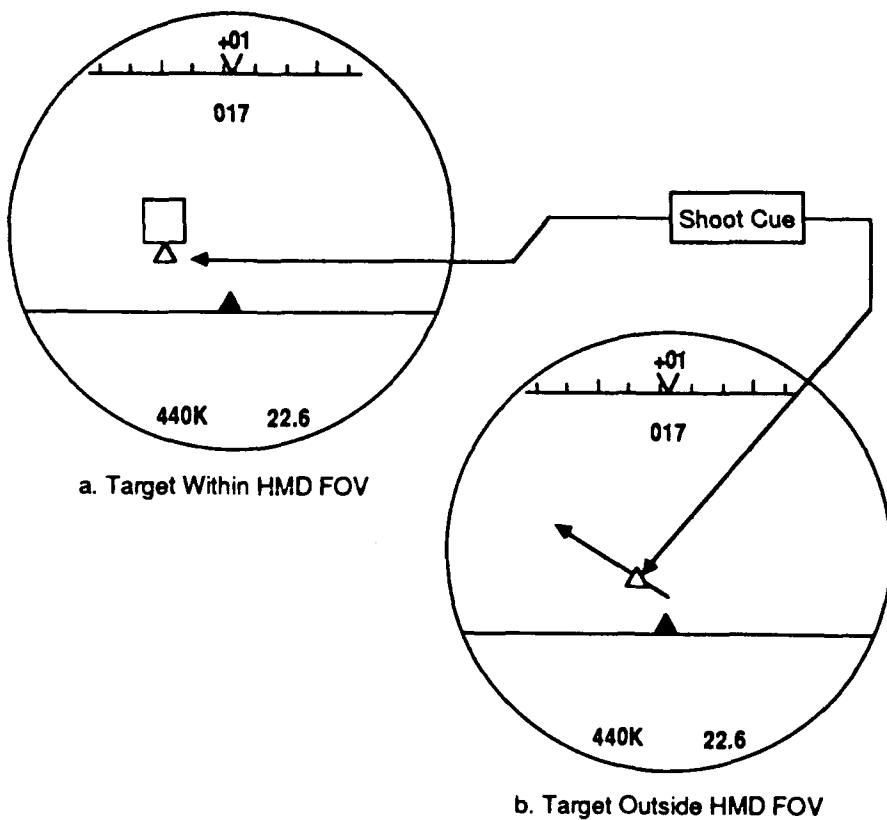
TCN	TACAN
TD	Target Designator
TDC	Target Designator Controller
TEWS	Tactical Electronic Warfare System
TF/TA	Terrain Following/Terrain Avoidance
TGT	Target
THRT	Threat
TL	Time Load
TOT	Time Over Target
TP	Target Pointer
TWS	Track While Scan
UFC	Up Front Control
UHF	Ultra High Frequency
VIS	Visual
WACQ	Wide Acquisition
WFOV	Wide Field of View
WPN	Weapon
WYPT	Waypoint

APPENDIX A
HELMET MOUNTED DISPLAY FORMATS

WEAPONS EMPLOYMENT

Three weapons-related symbols were provided: a Shoot Cue, a Sidewinder Seeker LOS Circle, and a Breakaway "X".

Missile Shoot Cue - When MRM or SRM was selected with the Weapon Select switch and the radar was in STT, a Shoot Cue was provided for the tracked target. When the target was within the HMD FOV, the Shoot Cue was provided for the tracked target. When the target was within the HMD FOV, the Shoot Cue was a triangle attached to the bottom of the TD box (the same symbol used on the current F-15 HUD). When the target was not in the HMD FOV, the Shoot Cue was a triangle embedded in the TP arrow 10 mils from the end of the arrow. Both symbols are illustrated in Figure A-1.



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Figure A-1. Missile Shoot Cue for Tracked Target

The criteria for this Shoot Cue were identical to those required for its display on the HUD. Like the HUD symbol, it flashes or remained steady as a function of target range when MRM was selected.

Sidewinder Seeker LOS (Aim-9 L/M) - The operation of the AIM-9 L/M seeker was changed to slave the seeker to the helmet LOS instead of aircraft boresight when the radar was in search or if manual boresight was selected. The possible cases are described below and illustrated in Figure A-2.

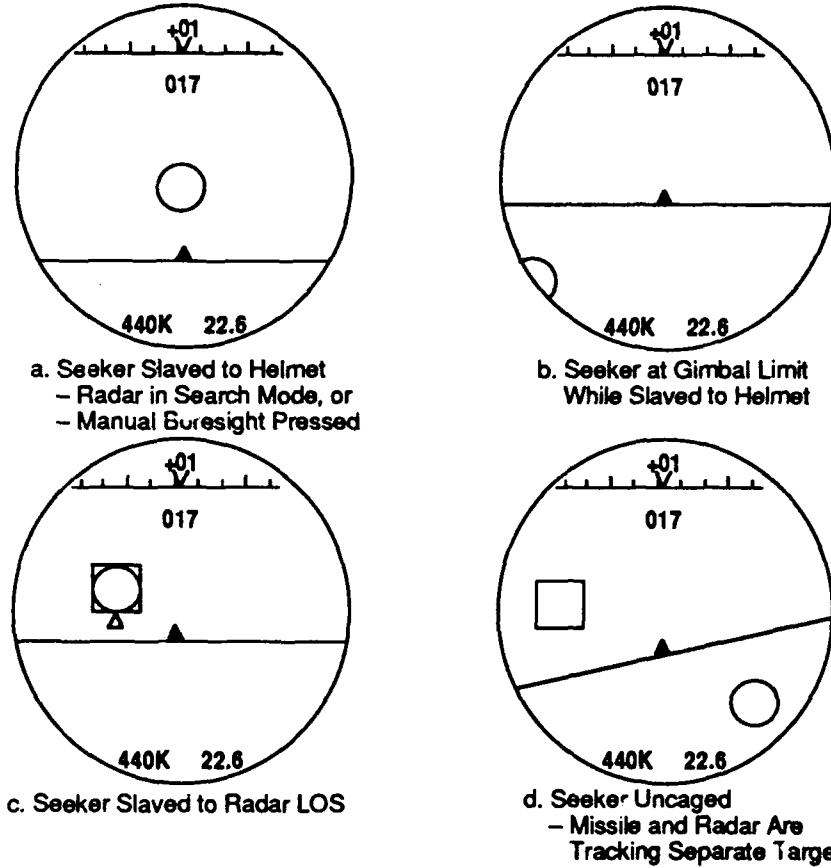


Figure A-2. AIM-9 L/M Sidewinder Displays

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a. Radar Not In Track - When the radar was in a search mode, the missile seeker was slaved to the helmet. This was indicated by display of the 25 mil Sidewinder Seeker Position Circle. If the helmet LOS was within the gimbal limits of the seeker, the seeker was slaved to the helmet LOS, and the seeker circle was displayed in the center of the HMD FOV, as shown in Figure A-2(a).

If the helmet LOS exceeded the seeker gimbal limits, then the missile seeker remained at the limit and its location relative to the helmet was indicated by a solid half-circle at the edge of the HMD FOV. This condition is shown in Figure A-2(b). If the pilot continued to move his head, the seeker remained at its gimbal limit, but it shifted in azimuth and elevation so as to remain on a radial from the helmet LOS to the aircraft boresight line. This continued until the HMD LOS was again within the seeker gimbal limits, at which time the seeker was again slaved to the helmet and moved in conjunction with head movements.

b. Radar Tracking, Seeker Slaved to Radar - When the radar tracked a target, the missile seeker was slaved to the radar LOS. The pilot could observe proper slaving by aligning his head so that the

radar/seeker LOS was within the HMD FOV. The pilot could then observe both the TD box, indicating the radar LOS, and the Sidewinder seeker position circle, indicating the seeker LOS. The pilot could determine whether the seeker was slaved to the radar by noting whether the seeker circle was superimposed over the TD box, as illustrated in Figure A-2(c). Note that when neither LOS was within the HMD FOV, the TP Arrow could be used to locate the tracked target.

- c. Radar Tracking, Missile Manually "Boresighted" - If the seeker was slaved to the radar LOS, depressing and holding the AIM-9 L/M Manual Boresight button on the right throttle slaved the seeker to the helmet in the same fashion as described above. Thus, when the helmet LOS was within the seeker gimbal limits, the seeker was slaved to the helmet LOS, and when the LOS exceeds seeker limits, the seeker remained the limit and the half-circle symbol was displayed on the HMD. The seeker remained slaved to the helmet while the Manual Boresight switch was held depressed, assuming the seeker was caged.
- d. Seeker Uncaged - The seeker was uncaged from any of the above locations by pressing the Uncage button on the Stick. The seeker would then attempt to enter self-track. The seeker position was indicated by the seeker circle, which was then positioned as required to indicate seeker LOS. Proper seeker tracking could be confirmed by observing the location of the seeker circle relative to either the TD box (target tracked by radar) or the actual aircraft (target visually acquired). Figure A-2(d) illustrates a situation where the radar and the AIM-9 missile are tracking separate targets.

This feature enabled the pilot to observe Sidewinder seeker status and launch the weapon at high off-boresight angles. Thus, using only the HMD, it was possible to visually acquire the target at a high off-boresight angle, lock on with the radar, uncage the AIM-9 seeker, confirm seeker track, and launch the missile (based on the Shoot Cue) without ever having had the target within the HMD FOV. In a short range situation the pilot could place the seeker directly onto the target using the HMD without radar acquisition.

Breakaway "X" - The Breakaway "X" symbol is shown in Figure A-3. It was displayed on the HMD whenever range to the radar tracked target was at or below minimum range for the weapon selected. It was displayed for the same conditions used for its display on the HUD and the VSD. The "X" was centered on the HMD FOV and blinked at a rate of 2.5 Hz. Each side of the X was 125 mils long.

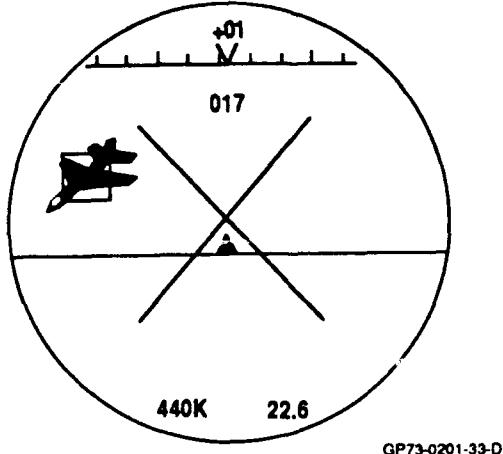


Figure A-3. Breakaway "X"

AIR-TO-AIR INTERROGATOR (AAI) OPERATION

The HMD displayed AAI symbols for targets when the radar was in STT, TWS, or RAM and the AAI button was depressed. Operation required prior AAI setup in terms of mode desired, codes to be interrogated, etc. The HMD served merely as an additional display medium which duplicated some VSD displays.

Symbol Used - Small circle and diamond symbols (similar to those provided on the VSD radar display) were used. The symbols were positioned at the top of the TD box, as shown in Figure A-4. The symbol used was identical to the symbol displayed on the VSD: diamond for non-Mode 4 or low confidence Mode 4 replies and a circle for high confidence Mode 4 replies.

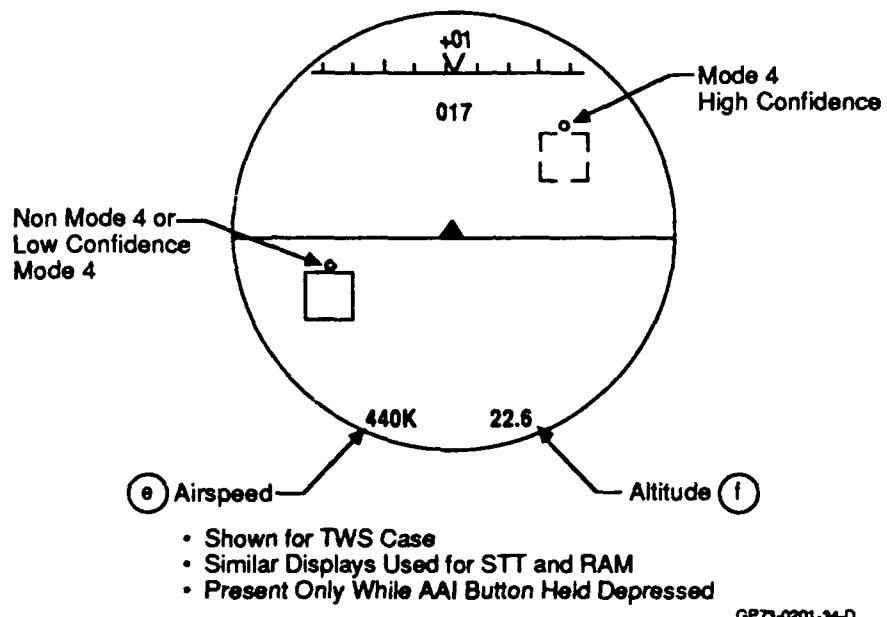


Figure A-4. AAI Reply Modes

Radar In Search (LRS, SRS, VS, PULSE) - No AAI displays were provided on the HMD when the radar was in a search mode.

Radar In STT - When the tracked target was located in the HMD FOV (TD box displayed), pressing the AAI button on the throttle resulted in interrogation of the tracked target. If the correct response is received, it was displayed above the TD box.

Radar In TWS - When TWS was in use, pressing the AAI button provided interrogation and display results on the VSD. Any target that had an established track file, provided the correct reply, and was located in the HMD FOV had its reply displayed over the appropriate TD box on the HMD.

Radar in RAM - When the radar was in RAM, the designated target had its AAI reply displayed in the same manner as discussed for STT. If RAM-Space is selected, no AAI reply was displayed on the HMD.

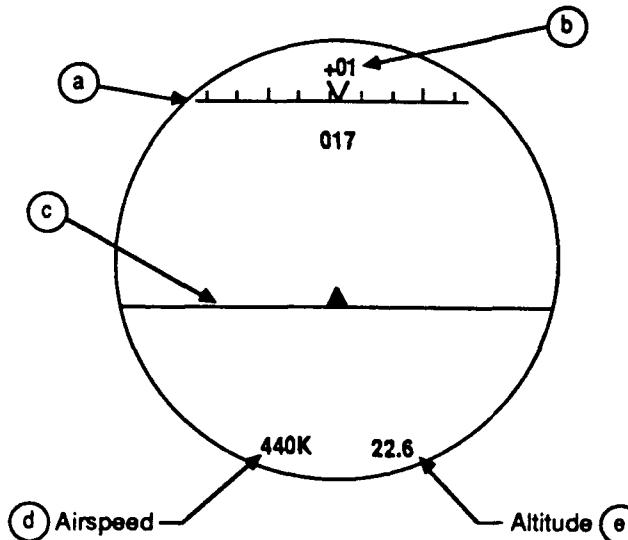
DECLUTTER MODES

Changes To HUD Symbology - Symbols displayed on the HMD were removed from the HMD. This was done to eliminate clutter caused by multiple symbols that were not exactly aligned (e.g. TD boxes). The following symbols were not displayed on the HMD while the HMD was in use.

- o Auto Acquisition Symbols (Supersearch, Vertical Scan, Boresight)
- o TD Box
- o Shoot Cue
- o Sidewinder Seeker Position Circle
- o Breakaway "X"

HMD SYMBOLS WHICH ARE ALWAYS AVAILABLE

Basic Display - The basic format present whenever the HMD was on is shown in Figure A-5. A description of display elements is provided below.



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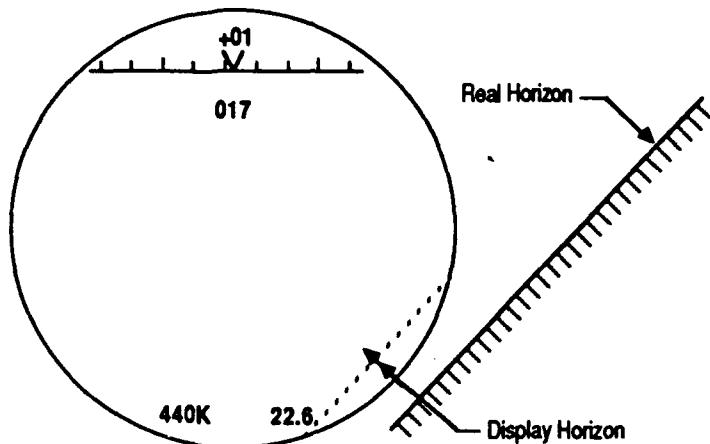
Figure A-5. Basic HMD Symbols

a. Heading Indicator and Scale - The digital heading indicator provided the pilot with orientation of his head/helmet. "Head/helmet orientation" meant the LOS established from the pilot's eye through the center of the HMD field of view (FOV). Note that this was normally different from aircraft heading.

The scale above the heading indicator provided the location of adjacent heading. The "tick" marks on the scale were plotted one degree apart for the present head elevation. This meant that the tick marks move closer together as the head was moved either up or down from the horizon. In the extremes, the heading scale "shrank" to a single line when the head was pointing towards zenith or nadir (90° to the horizon).

- b. Head Elevation - The two digit number above the heading scale indicated elevation angle of the head/helmet in degrees relative to the horizon. Elevation angles above the horizon were prefixed with a positive sign (+), and angles below the horizon were prefixed with a negative sign (-).
- c. Horizon Bar - The location of the real world horizon relative to head orientation was indicated by the horizon bar. The triangle symbol in the center of the bar was a sky pointer and was displayed on the "sky" side of the bar.

The horizon bar was always drawn parallel to the real horizon. When the real horizon was within the HMD FOV, the horizon bar was aligned with it and overlaid the real horizon. When the real horizon was outside the HMD FOV, the horizon bar was displayed as a dashed line at the edge of the display FOV, but it remained parallel to the real horizon. This case is shown in Figure A-6.



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Figure A-6. Display-Limited Horizon Bar

It should be noted that the horizon bar indicated horizon location, NOT aircraft attitude. However, the bar did provide an extreme attitude warning.

- d. Calibrated Airspeed (CAS) - Calibrated airspeed was displayed to the nearest knot on the left at the bottom of the display. It was distinguished from altitude by the "K" symbol (knots) which followed the digits. All digits were drawn full size (approximately 5 mils x 7 mils).

The CAS indicator provided a slow speed warning. Whenever it is 200 knots or less, the CAS digits blinked at 1 Hz.

- e. Mean Sea Level (MSL) Altitude - MSL Altitude was displayed on the right at the bottom of the display. A decimal point separated thousands of feet from hundreds of feet (e.g. "22.6" indicates 22,600 ft. MSL).

Extreme Attitude/Ground Proximity Warning - The system provided a warning of extreme attitudes as a function of ground proximity. The warning was provided whenever either of the following conditions occurred:

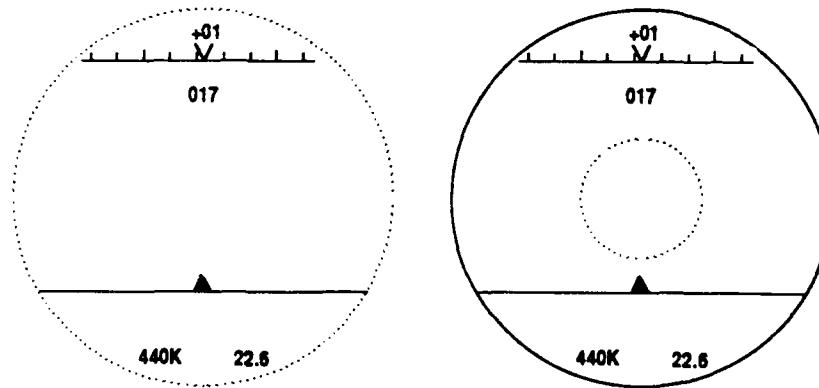
- o Dive Angle greater than 30°, less than 60°, and altitude at or below 5000 ft. MSL.
- o Dive Angle 60° or greater and altitude at or below 10,000 ft MSL.

When either of these conditions was present, the horizon bar flashed at a rate of 2.5 Hz. These combinations were chosen to provide sufficient altitude for dive recovery prior to ground impact.

A/A RADAR TARGET ACQUISITION

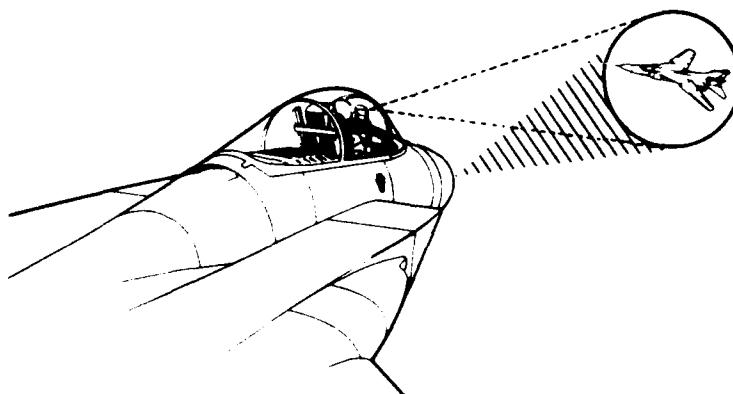
The HMD could be used to direct automatic acquisition of targets with the air-to-air (A/A) radar. The forward position of the auto acquisition switch on the stick grip was used for this purpose. When the radar was in a search mode, depressing the auto acquisition switch in the forward position selected Helmet Supersearch (HSS). The F-15 Supersearch scan was performed, but the scan was centered at the HMD LOS instead of radar boresight. This pattern was indicated on the HMD by a dashed circle that is 120° in diameter. This is shown in Figure A-7(a).

Depressing the auto acquisition switch forward a second time selected Helmet Boresight (HBST). In this mode, the radar antenna was slaved to the helmet LOS. This mode provided more precision than HSS and accomplished faster lock-ons. This mode was displayed by a 40° dashed circle located in the center of the HMD FOV, as shown in Figure A-7(b).



a. Helmet Supersearch (HSS) Display

b. Helmet Boresight (HBST) Display



c. Radar Slaved to Helmet LOS

Figure A-7. Helmet Automatic Acquisition Modes

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In both modes, the area covered by the radar antenna was centered on the helmet LOS and was slaved to the helmet until radar lock-on. The pilot needed only to move his head until the visually detected target was within this circle, at which time the radar acquired and tracked the target. The radar searched this area in range from 500 ft. to 10 NM until a target was acquired.

The radar remained slaved to the helmet unless the helmet LOS exceeds the radar gimbal limits (60° off boresight). When the helmet LOS exceeded 60° off boresight, the radar antenna remained at the limit on a radial to the LOS location. The antenna was indicated by a small half-circle at the edge of the HMD FOV on that radial. This circle was also dashed, but it was only 20° in diameter. This condition is shown in Figure A-8. If the pilot moved his head, the antenna remained at the gimbal limit, but it shifted in azimuth and elevation so as to remain on a radial from the helmet LOS to the boresight.

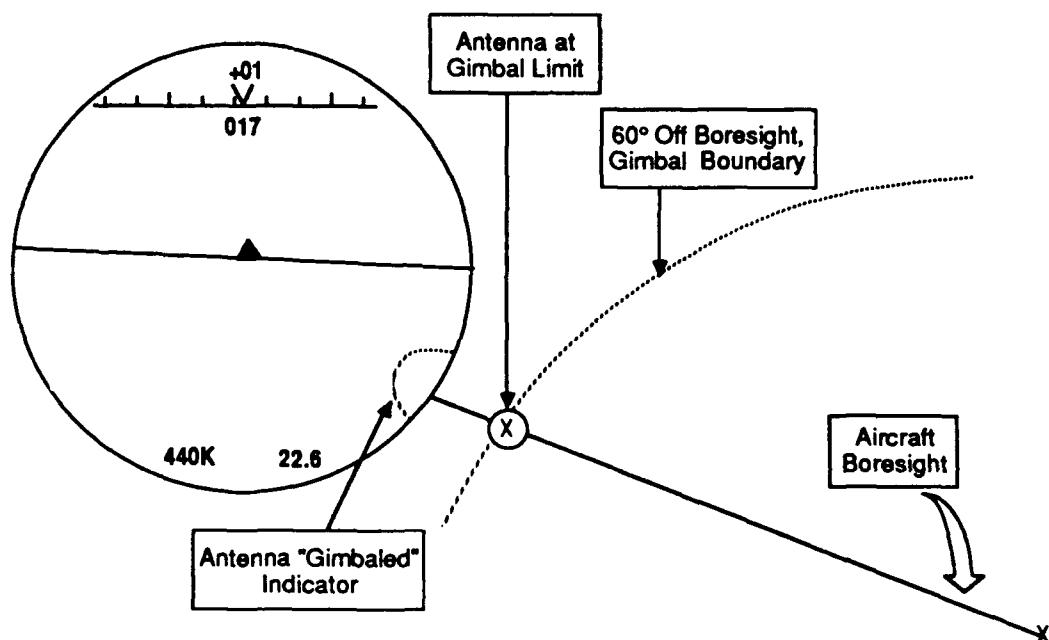


Figure A-8. Helmet Automatic Acquisition Display
When Radar Antenna Is at Gimbal Limits

GP73-0201-28-D

Repeated depression of the auto acquisition switch in the forward direction resulted in the radar alternating between HSS and HBST modes, similar to the way it would alternate between Supersearch and Boresight modes in the present F-15. The radar remained in the last selected acquisition mode (HSS or HBST) until the target was acquired or the pilot selected Return to Search (RTS).

When the HMD avionics were in use, no Vertical Scan mode was available. The Vertical Scan position (aft) on the automatic acquisition switch was then inoperative with the radar in search. When the radar is in track, the normal TWS functions of this switch position were available.

RADAR RELATED DISPLAYS

The HMD extended many of the HUD displays available when the radar was in track. The displays provided were a function of radar operating mode.

Search Modes (LRS,SRS,VS,PULSE) - No radar related symbols were provided when the radar was in a search mode. However, if HSS or HBST was selected, the antenna position symbol appeared, as described in Paragraph 7.5.

Single Target Track (STT) - When the radar is in STT, one of two symbols was present on the HMD: the Target Designator (TD), which was a box positioned at the target LOS; or the Target Pointer (TP), which was an arrow pointing toward the target. Both symbols are illustrated in Figure A-9.

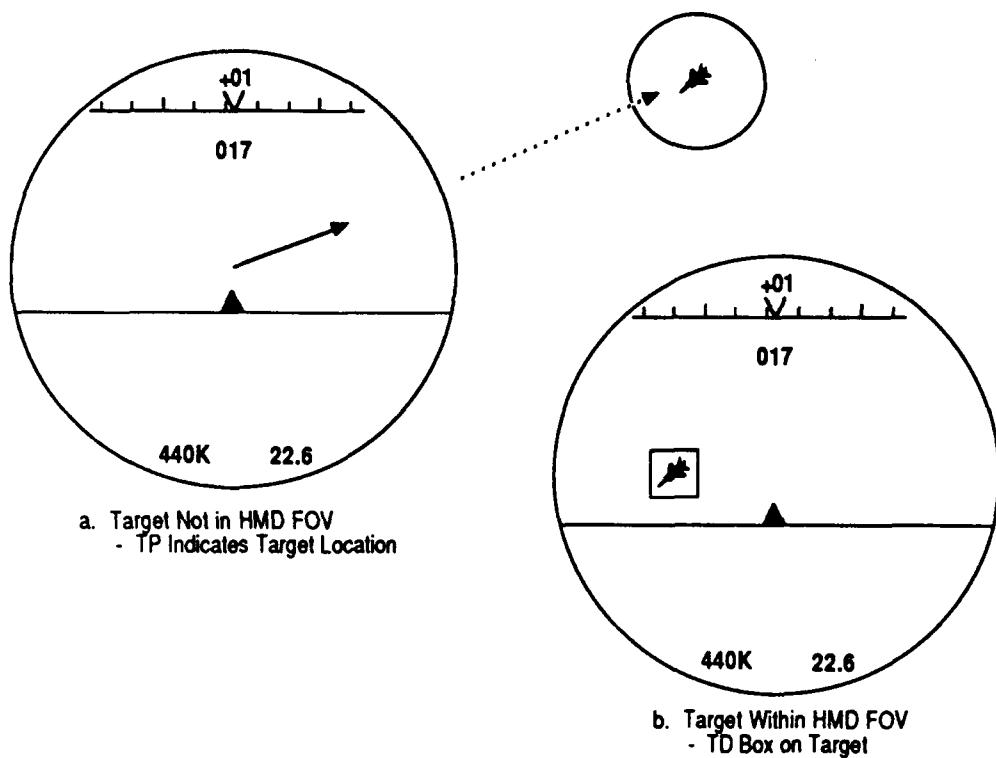


Figure A-9. STT/RAM Displays

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If the target was not located within the HMD FOV, then the TP arrow was present. The TP arrow radiated from the center of the HMD FOV to the target. By moving his head in the direction indicated, the pilot could align the helmet LOS to the radar LOS and locate the TD box.

The TD box was a square 25 mils on each side. The length of the TP arrow was fixed at 50 mils until the target was within 45 degrees of the helmet LOS. Then, it shortened at a rate of 1 mil/degree until the target was within the HMD FOV (arrow is approximately 11 mils long). Once the target was within the HMD FOV, the TD box appeared around the target, and the TP arrow disappeared.

The two symbols were mutually exclusive; there was no situation when both could be displayed at the same time.

Track While Scan (TWS) - In TWS mode the pilot was provided with multiple TD boxes as shown in Figure A-10. These indicated the position of all track files located within the HMD FOV. The priority designated target (i.e., the "starred" target on the radar display) was indicated by a solid TD box. All other targets were indicated by a segmented TD box.

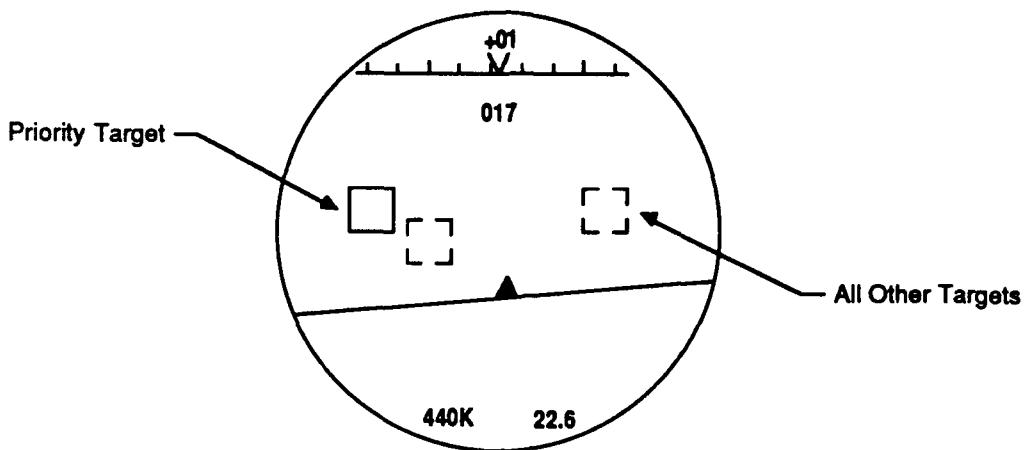


Figure A-10. TWS Display

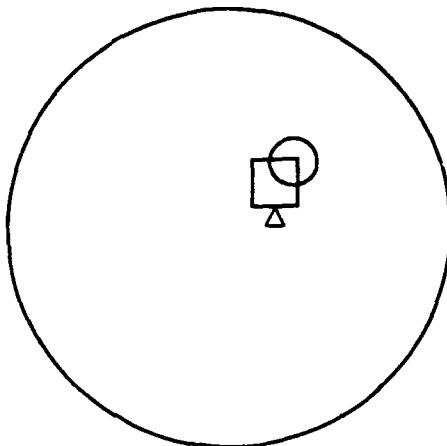
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The TP arrow was used to show the location of the priority designated target whenever it was not within the HMD FOV. The length of the TP arrow was determined in the same manner as described above for STT mode. The TP arrow was mutually exclusive with the solid TD box.

Raid Assessment Mode (RAM) - In RAM mode, a single TD box was available at the LOS of the designated target. When this target was outside the HMD FOV, the TP arrow was present to indicate its position. When the target was within the HMD FOV, a solid TD box was provided. Essentially, the STT displays were provided with the designated target treated as the "tracked" target. Other targets detected were displayed only on the VSD not the HMD.

If the RAM-Space mode was selected by designating a space, a single segmented TD box was provided at the LOS of the designated space point. The TP arrow was displayed when the space point LOS was outside the HMD FOV.

Symbols Reject - The pilot could manually declutter the HMD by selecting "Symbols Reject" on the HUD control panel. This eliminated all basic symbology and inhibited attitude warning. All weapons-related symbology continued to operate, as shown in Figure A-11. The normal Symbols Reject HUD display also resulted. Thus, it was not possible to declutter one while leaving a full display on the other.



- Shown for Case of Radar in STT, SRM Selected, Seeker Uncaged, Shoot Cue Present
- Other Symbols Available Include Helmet Aquisition Circles, Sequenced TD Box, TP Arrow, Break "X", and AAI Reply Symbols

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Figure A-11. Typical Symbols Reject Display

HMD Blanking - The pilot could blank the HMD by pressing and holding the HMD blanking switch on the left throttle. While this switch was depressed, all symbols were removed from the HMD. Releasing the switch restored HMD symbology.